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EXAMINING UNDERWATER VISUAL CENSUS TECHNIQUES FOR THE ASSESSMENT OF POPULATION STRUCTURE AND BIODIVERSITY IN TEMPERATE COASTAL MARINE PROTECTED AREAS

Edited by Neville Barrett and Colin Buxton

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Enquires should be directed to the series editor:
Dr Caleb Gardner
Marine Research Laboratories,
TAFI, University of Tasmania
PO Box 252-49, Hobart, TAS 7000, Australia

Examining Underwater Visual Census techniques for the assessment of population structure and biodiversity in temperate coastal marine protected areas

Marine Research Laboratories, Hobart,

14 - 15th October 1999

Edited by Neville Barrett and Colin Buxton

Tasmanian Aquaculture and Fisheries Institute
Marine Research Laboratories

A WORKSHOP SPONSORED BY FRDC, THE TASMANIAN AQUACULTURE AND FISHERIES INSTITUTE AND THE VICTORIAN DEPARTMENT OF NATURAL RESOURCES AND ENVIRONMENT.

State Government Victoria Department of Natural Resources and Environment

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

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Summary

The Tasmanian Aquaculture and Fisheries Institute and the Victorian Department of Natural Resources and Environment conducted a two day joint workshop in October 1999 to examine underwater visual census techniques for the assessment of population structure and biodiversity in temperate coastal marine protected areas. The proposed outcome of the workshop was to establish a consensus on the most appropriate methodologies to use and to standardise methodologies across the temperate Australian states. The workshop goals included determining the types and magnitude of biotic change we want to detect, examining UVC techniques currently in use worldwide, and exploring alternative techniques.

A clear outcome from the workshop was that as the current round of MPAs are being developed from a biodiversity perspective, most managers felt that monitoring should be related to this. Because biodiversity is such a broad concept, monitoring should also be broadly based, involving sampling at a range of scales from seascapes, through communities, to populations of individual species. Gary Davis outlined how such a broadly based monitoring program was developed in the Californian Channel Islands.

The availability of funding was identified as a major limiting factor in establishing broadly based monitoring programs, and it was clear that funding will be predominantly a state responsibility and be related to individual MPA management. To give an indication of what can be achieved within the current Australian funding network, Hugh Sweatman discussed the types of monitoring being conducted on the GBR with moderate funding, and Graham Edgar discussed monitoring on a shoestring budget in Tasmanian MPAs. Managers will have to accept that existing resources are limited and monitoring programs need to be targetted and have clear and achievable goals. To achieve these goals we need good experimental design, and Mick Keough discussed ways of achieving this with MPAs. One of the most critical points in this design is in determining the effect size that we consider significant.

The discussion on this subject, including the types of change as well as magnitude, ranged widely from habitats to individual species. Although there was no overall consensus, it was considered at the species level, a 100% change in abundance and a 20% change in mean size might be significant in many cases.

Representatives from individual states and the Commonwealth indicated that monitoring in temperate MPAs was currently limited, with the exception of Tasmania and a program currently being developed in Victoria. This lack of monitoring is in part related to the lack of MPAs in many areas as yet, and partly due to funding restrictions. Current monitoring programs are focused on visual census of reef communities for practical purposes although many managers indicated that broader monitoring was desired, including other habitats, and species.

A discussion aimed at developing a consensus on appropriate visual census methodology accepted that the current techniques in use in the Tasmanian and Victorian studies were valid, and that with sufficient replication of sites, would detect the types and magnitude of changes that were of interest to managers. This methodology is restricted to shallow reefs however, and many of the managers present were interested in exploring and developing methodologies over a wider range of habitat types and species, with some questioning the value of adopting a standard methodology between states. It was evident that if a standard and broadly based methodology is to be developed, a series of workshops will be needed, each examining clearly defined habitats, species and techniques.

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1. Introduction

The Tasmanian Aquaculture and Fisheries Institute (TAFI), in association with the Victorian Department of Natural Resources and Environment (NRE), conducted a workshop on monitoring temperate marine protected areas on the 14-15th of October 1999. The aim was to bring together scientists and managers involved in monitoring MPAs to discuss the most appropriate methodologies used and their standardisation across temperate Australia. Field demonstrations of survey techniques were held after the workshop. Guest speakers with extensive experience in temperate and tropical MPA monitoring and effective statistical design were invited to the meeting.

With the development of a national system of marine protected areas (NSRMPA) in Australia, it is important to establish effective monitoring programs to evaluate the before and after effects of protection. As the underlying theme of the NRSMPA is the conservation of biodiversity, it is necessary to monitor and quantify biodiversity changes in MPAs relative to reference sites. This will also enable an identification of the important threatening processes and their magnitude. If the magnitude of the threats is substantial, one needs to evaluate management strategies for the remaining coastline, because MPAs generally only protect diversity at the local scale (individual MPAs), and adequate conservation of biodiversity requires effective management of the entire system of which the reserved areas form a part. At the local scale one needs to know if the size, shape, location and management plan chosen for each MPA is adequate for it to achieve intended aims.

While the current process of MPA establishment is related to the conservation of biodiversity, MPAs may act in a number of different roles, including fisheries enhancement and as a reference area for fisheries and/or conservation management. It is important that monitoring programs are designed to assess these roles as well. The Tasmanian Aquaculture and Fisheries Institute is currently examining the fisheries related benefits of MPAs and aims to ensure the current underwater visual census techniques used in this study are appropriate for the task. The Victorian Department of Natural Resources and the Environment. NRE is currently trialing a program to monitor and report on the state of marine biodiversity in Victorian waters. The workshop was therefore designed to also inform these projects.

As underwater visual census techniques are the most commonly used methods for monitoring biotic change in coastal MPAs, the workshop aimed to compare and assess variations of this technique currently in use. - Hence the workshop title, “Examining underwater visual census techniques for the assessment of population structure and biodiversity in temperate coastal marine protected areas”. The proposed outcome of the workshop was to establish a consensus on the most appropriate methodology for standard usage across temperate Australian states. This standardisation would allow effective comparison between states. To achieve this outcome, four goals were identified. These were to:

1. Identify the types and magnitude of biotic change to be detected.

2. Examine the success of underwater visual census (UVC) techniques currently in use in Australia and overseas for monitoring biotic change and discuss the relative merits of each technique.
3. Discuss alternative or supplementary methods in use for performance assessment.
4. Establish a consensus on appropriate standard UVC methodology for use in temperate Australia.

To help achieve these goals, keynote speakers were invited to share their experiences in long term monitoring and in appropriate experimental design. The first of these was Dr Gary Davis from the Channel Islands National Park in California. This temperate zone marine park was established in 1980, and from its inception has been the focus of a detailed and broadly based *vital signs* monitoring program, yielding invaluable information on the benefits of marine parks in identifying human impacts on coastal processes.

The second keynote speaker was Dr Hugh Sweatman from the Australian Institute of Marine Science. Hugh is involved with the AIMS long term monitoring program, an extensive program that began in 1993, building upon existing monitoring programs. While this is a tropical program, many of the techniques, and the difficulties encountered, are in common with the temperate zone.

The third keynote speaker was Dr Graham Edgar from the Tasmanian Aquaculture and Fisheries Institute. Following the establishment of Tasmania's first MPAs in 1991, Graham was involved in the establishment of baseline monitoring, that, with opportunistic funding of annual surveys in the intervening years, has resulted in the longest-term monitoring program in temperate Australia.

The final keynote speaker was Dr Mick Keough from the Zoology Department of the University of Melbourne. Mick is a biologist/statistician with extensive experience in the appropriate statistical design of experiments examining coastal processes in temperate Australia, and has been involved in assessing the power requirements of MPA monitoring programs.

In addition to the keynote speakers, representatives from each of the temperate states, and the Commonwealth, were invited to give a presentation outlining any existing state monitoring programs, the information requirements they may need from a monitoring perspective, and the current status of MPAs in their state. A particularly important component in this session was in establishing the types of change that state agencies wanted to detect.

Following the keynote speakers and state representative presentations, and armed with an understanding of current studies, methodologies, difficulties, information requirements, and the need for an appropriate statistical design, an extended open discussion session was held. The focus of this discussion was identifying the types and magnitude of biotic chance we want to be able to detect, and practical sampling designs for achieving this.

The next session examined the current UVC techniques used in Australia and overseas for monitoring biotic change, and involved talks by Dr Neville Barrett (UVC techniques for fish), Dr Matthew Edmunds (techniques for lobster abundance estimation), and Dr Rick Officer (abalone abundance estimation). These talks formed the framework for open discussions on the merits of various techniques in MPA monitoring.

In the final session, there was an open discussion on possible alternative methods to UVC, and an attempt at developing a consensus on an appropriate standard UVC methodology for the assessment of population structure and biodiversity in temperate coastal MPAs.

As this workshop was primarily an interactive one, with extensive group discussions, the proceedings have been published with a mix of formal papers from the keynote speakers and some state representatives, along with detailed notes on the group discussions. These discussions, while difficult to summarise, make for interesting reading. They raise as many questions as they answer, however this gives the reader a good indication of the range of issues involved in developing effective monitoring programs in temperate MPAs, when viewed from the perspective of managers, statisticians and biologists.

1.1 Workshop Program

TASMANIAN AQUACULTURE AND FISHERIES INSTITUTE / VICTORIAN DEPARTMENT OF NATURAL RESOURCES AND ENVIRONMENT WORKSHOP

Examining Underwater Visual Census techniques for the assessment of population structure and biodiversity in temperate coastal marine protected areas

TAFI Marine Research Laboratories, Hobart,

14 - 15th October 1999

Background

An important component of the establishment of MPA's is the initiation of effective monitoring programs to evaluate the before and after effects of protection. These programs enable us to determine if the MPA's are meeting their intended roles, such as the enhancement of fishery stocks or the conservation of marine biodiversity. Underwater visual census is the most common technique used for monitoring biotic change in coastal MPA's. This workshop will compare and assess the variations of this technique currently in use.

The proposed outcome is to establish a consensus on the most appropriate methodologies and their standardisation across temperate Australian states.

The goals of the workshop are to:

1. Identify the types and magnitude of biotic change we wish to detect.
2. Examine the success of underwater visual census (UVC) techniques currently in use in Australia and overseas for monitoring biotic change and discuss the relative merits of each technique.
3. Discuss alternative or supplementary methods in use for performance assessment.
4. Establish a consensus on appropriate standard UVC methodology for use in temperate Australia.

PROGRAM

DAY 1 - 14TH OCTOBER

Session 1. Current studies and methodologies

Chairperson - Colin Buxton

0900 - 0905 *Welcome* - Colin Buxton

0905 - 0915 *Introduction* - Graham Edgar and Lawrance Ferns

0915 - 1010 Keynote address: *The Channel Island Marine Reserve (California) long term monitoring project* - Gary Davis

1010 -1050 Keynote address:*Long term monitoring program in the Great Barrier Reef Marine Park* - Hugh Sweatman

1050 - 1105 Tea

1105 - 1145 *Long term monitoring in Tasmanian marine reserves* - Graham Edgar

State and Commonwealth Perspective's -
Information requirements, the current status of MPA's and MPA monitoring programs

1145 - 1200 *ANZEEC - its role in performance assessment of MPA's* - Bernadette O'Neil

1155-1200 Monitoring as a responsibility of the Commonwealth - Nancy Dahl-Tacconi

1200 - 1215 *New South Wales* - Tim Lynch

1215 - 1230 *South Australia* - Romola Stewart

1230 - 1245 *Victoria* - Lawrance Ferns

12.45 - 1300 *Tasmania* - Karen Edyvane

1300 - 1400 Lunch

Session 2. Practical statistical design requirements

Chairperson - Malcolm Haddon

1400 - 1430 Keynote address: *Appropriate statistical designs for detecting biotic change in MPA's* - Mick Keough

1430 - 1530 *Open discussion - Types and magnitude of biotic change*
Practical sampling designs

1530 - 1600 Tea

Session 3. Underwater visual count techniques

Chairperson - Graham Edgar

1600 - 1620 *UVC techniques currently in use in temperate Australia* - Neville Barrett

1620 - 1700 *Open discussion - Appropriate UVC techniques*

DAY 2 - 15TH OCTOBER

Session 3 (continued). Underwater visual count techniques

Chairperson - Graham Edgar

0900 - 0910 *UVC techniques for examining rock lobster populations* - Matthew Edmunds

0910 - 0930 *Open discussion on censusing lobsters*

0930 - 0940 *UVC techniques for examining abalone populations* - Rick Officer

0940 - 1000 *Open discussion on censusing abalone*

Session 4. Alternative methods

Chairperson - Laurance Ferns

1000 - 1100 *Open discussion - Alternative techniques such as trapping, potting, bait stations and video, that may yield more robust data than UVC, be more cost effective, or allow operation beyond diving depths*

1030 - 1100 Tea

Session 5. Towards developing a consensus on appropriate standard UVC methodology

Chairperson - Gary Davis

1100 - 1230 *Open discussion - Current models and alternatives*

1230 - 1245 *Achieving a consensus on UVC techniques*

1245 - 1300 *Workshop summary* - Colin Buxton

1300 Lunch

This workshop was kindly sponsored by a grant from the Fisheries Research and Development Corporation.

1.2 Invited participants

Keynote speakers

Gary Davis (Channel Islands National Park, California)

Hugh Sweatman (Australian Institute of Marine Science, Townsville)

Mick Keough (Zoology Department, University of Melbourne)

Western Australia

Chris Simpson (Department of Conservation and Land Management, Western Australia) (Withdrew at last moment)

South Australia

Romola Stewart (Department of Environment, Heritage and Aboriginal Affairs, South Australia)

John Gilliland (Department for Primary Industries, South Australia)

New South Wales

Tim Lynch (Jervis Bay Marine Parks Authority, New South Wales)

Nick Ottway (Fisheries, NSW)

Commonwealth

Janet Slater (Environment Australia, Commonwealth MPA's)

David Harasti (Environment Australia, Coastal Monitoring Program)

Bernadette O'Neil (Environment Australia, Marine Group, Marine Protected Areas Section)
Nancy Dahl-Tacconi (Environment Australia, Commonwealth MPA's)
Barbara Jones (Environment Australia, Marine Group, Marine Protected Areas Section)

Tasmania
Peter Bosworth (Department of Primary Industry, Water and Environment, Tasmania)
Karen Edyvane (Department of Primary Industry, Water and Environment, Tasmania)
Graham Edgar (Tasmanian Aquaculture and Fisheries Institute)
Neville Barrett (Tasmanian Aquaculture and Fisheries Institute)
Colin Buxton (Tasmanian Aquaculture and Fisheries Institute)
Malcolm Haddon (Tasmanian Aquaculture and Fisheries Institute)
Rick Officer (Tasmanian Aquaculture and Fisheries Institute)

Victoria
Matthew Edmunds (Consultant, Victoria)
Laurie Ferns (Natural Resources and Environment, Victoria)
Leanne Gunthorpe (MAFRI Queenscliff Laboratories, Victoria)

Guests
Alan Butler (CSIRO Marine Laboratories, Tasmania)
Craig Johnson (Zoology Department, University of Tasmania)
Sam Ibbott (Tasmanian Aquaculture and Fisheries Institute)
Caleb Gardner (Tasmanian Aquaculture and Fisheries Institute)
Alastair Morton (Tasmanian Aquaculture and Fisheries Institute)

2. Workshop Introduction – Graham Edgar

We feel that this workshop is an important one. It certainly comes at the crucial stage for us because we need to decide on methodology for monitoring reefs at a large southern Australian spatial scale as part of a new FRDC project. We also know that people in other states are involved in, or in the process of commencing, similar work, and feel that great benefits can be gained by standardising methodology between the different researchers wherever possible, and identifying the pros and cons of the various methodologies used by different groups. With respect to our own work, we have generally been happy with our censusing protocols, but strongly feel the need to compare out techniques with others to identify weaknesses, to determine ways of improvement, or in fact to find out whether competely new techniques are needed.

In Tasmania, we have been censusing reefs for 7 years and I guess can make some claim to having the third longest reef monitoring program worldwide. The longest reef monitoring program has been carried out in California, and we are very fortunate to have Dr Gary Davis here to provide us with insights into that study. The other major long-term reef study has been run by Dr Hugh Sweatman at AIMS, and we are similarly pleased to have him here also.

Decisions on census methodology are inevitably linked with questions of statistical and analytical techniques, particularly with respect to assessment of statistical power. Trade-offs inevitably need to be made between techniques, sample size, sampling time, number of replicates, number of sites sampled and spatial distribution of sites. As part of this forum, we therefore thought it necessary to include a major workshop component on statistical analysis of long-term monitoring data, and perhaps spend about half the time discussing these issues. Clearly, identifying appropriate statistical protocols should be done at the start rather than at the end of any project. In this context it is great to see Dr Mick Keough could make it here today to lead the discussion, particularly as his work commitments are such that he must rush back to Melbourne late this afternoon.

Thank you all for coming and providing your ideas.

3. Session 1. Current studies and methodologies – Chaired by Prof Colin Buxton

This session began with keynote addresses examining three of the world's longest running monitoring programs in MPAs.

3.1 Gary Davis – The Channel Islands National Park monitoring project.

The first keynote address was by Dr Gary Davis from the Channel Islands National Park. Gary discusses the Environmental Vital Signs Monitoring Project in the CINP.

3.2 Hugh Sweatman - Long term monitoring in the GBR.

The second keynote address in this session is from Hugh Sweatman from AIMS. Hugh is involved with a long-term monitoring program in the Great Barrier Reef. This extensive program was established in 1991, but has its roots in longer term monitoring of crown-of-thorns, dating back to the early 1980's.

3.3 Graham Edgar - Long term monitoring in Tasmanian MPAs.

The third keynote address in this session is by Graham Edgar from TAFI. Graham is involved with a long-term monitoring program examining biotic change in Tasmanian MPAs. This program was established in 1992.

The presentations are given below.

Environmental V*ital Signs* Monitoring to Assess Marine Protected Area Performance

A Case Study from Channel Islands National Park, California

Gary E. Davis

Channel Islands National Park
1901 Spinnaker Drive, Ventura, California 93001-4354 USA
Phone (805) 658-5707–FAX (805) 658-5799
gary_davis@nps.gov

Introduction

Channel Islands National Park was established in 1980 to preserve unimpaired, self-sustaining examples of coastal ecosystems off the coast of southern California. Roughly half of the 101,000 ha park is underwater. Five of the eight California Channel Islands comprise the other half. Many governmental bodies have conferred a variety of conservation designations on these islands and the sea around them (Table 1), but none of these conservation designations prohibits fishing. A small part of the Anacapa Island Ecological Reserve (15 ha) protects all marine life from human taking. This paper describes the design, structure, and function of a *vital signs* monitoring program instituted to inform, guide, and evaluate performance of natural resource preservation efforts in Channel Islands National Park, California. The National Park Service leads an informal coalition of Federal and State agencies and private interests that sponsors and funds this *vital signs* program, each acting under its aegis.

The National Park Service mission[1], the ecology of the Channel Islands, and regional human threats to park resources combine to determine the function–and thereby the structure–of the *vital signs* Monitoring program. The *vital signs* program has four goals. It seeks to:

- identify and measure ecological vital signs of park ecosystems to determine their present and future health,
- establish empirically normal limits of variation of resources and ecological processes,
- diagnosis abnormal conditions early, when they are manageable, and
- identify potential agents of abnormal change, to help frame research and prescribe treatments.

Establishing cause and effect relationships among multiple stresses and resource dynamics requires extensive experimental manipulation and was beyond the scope of the *vital signs* monitoring program. This program was designed to diagnose environmental problems and evaluate treatments, but did not attempt to replace hypothesis-driven research.

[1] To preserve unimpaired park resources for the enjoyment, education, and inspiration of this and future generations

Threats to park resources that helped shape *vital signs* sampling design include:

– unsustainable uses, such as fishing, grazing, and disturbance by visitors;
– fragmentation of habitats, including loss of nearby mainland habitat and island erosion;
– pollution of air and water;
– spread of alien species, and
– loss of soil and fog-drip precipitation.

In this situation, measures of population dynamics served as good ecological vital signs, especially measures of abundance, geographic distribution, age structure, reproduction, juvenile recruitment, and growth and mortality rates. Basic environmental parameters, such as sea temperature, precipitation, and other meteorological measures also were identified as vital signs. Collectively, these population and environmental parameters permitted projections of future conditions which gave early warnings of impending disasters. The selected taxa integrated a broad variety of environmental and human induced stresses, thereby detecting subtle chronic stresses as well as defining critical acute events. These environmental *vital signs* also directly measured effects of remedial actions, such as alien species control and mitigation of visitor disturbances, which facilitated adaptive management.

Table 1. Conservation designations of the California Channel Islands in and adjacent to Channel Islands National Park.

International Biosphere Reserve (designates special recognition for conservation and education)
National Marine Sanctuary (protects seabed and air space)
National Oil and Gas Sanctuary (prohibits petroleum exploration and exploitation)
National Park (preserves island and marine ecosystems)
State Ecological Reserve (regulates fishing)
• San Miguel Island Ecological Reserve
• Anacapa Island Ecological Reserve
• Santa Barbara Island Ecological Reserve
State Area of Special Biological Significance (ASBS) (regulates water quality)
• Santa Rosa Island ASBS
• Santa Cruz Island ASBS
State Area of Environmental Concern (regulates land use)
University of California Santa Cruz Island Nature Reserve (identifies research site)
The Nature Conservancy Santa Cruz Island Project (preserves island ecosystems)

Identifying and measuring *vital signs* of ecosystems were difficult and complex endeavors in this park. It involved more than 40 discrete, but interdependent, activities or projects conducted over nearly ten years. This complexity and the magnitude of the work tends to overwhelm those who are faced with similarly threatened natural resources and constrained by severely limited fiscal and personnel resources. The complexity was reduced and organized into a four-step process. This facilitated explaining the need for a *vital signs* program and marketing *vital signs* monitoring to potential supporters and collaborators. This process also allowed all participants and supporters to see easily how their contributions related to the whole effort.

After setting *vital signs* goals, as indicated above, the next three steps were to:
1) develop a conceptual ecosystem model of the park,
2) conduct design studies of ecosystem components to establish monitoring protocols, and
3) implement monitoring.

Decomposing the overwhelming job of designing and implementing a monitoring program into feasible tasks and fundable projects helped overcome inertia, facilitated communication among participants, and provided a record for future generations of participants to see how and why particular components and parameters were selected.

Successful conservation at the close of the 20th century requires coalitions of many interests. The example described here may appear to be an ideal, with near-adequate professional staff and funding, but it began in 1980 with one person and no other resources. Only the commitment of a park superintendent to science-based management and a single sentence in an obscure Federal law that allocated no funding but nevertheless required “an inventory of all species, both marine and terrestrial…with biennial reports…for ten years” spawned this pioneering program (16 USC 410ff).

Four-step Design Process

The process used to design and implement the Channel Islands National Park *vital signs* monitoring program was described and marketed using a step-down diagram that showed explicitly both the relationships among the 41 detailed technical program elements and between every element and the park’s mission (Phenicie and Lyons 1973, Davis 1993). A step-down diagram starts with program goals on the top line and on the line below indicates all of the actions–and only those actions–required to achieve the goals on the line above it. The actions on the second line become the goals for the next step down, indicated on the third line. This step-down process continues to decompose large complex tasks or programs into feasible actions until the actions on the bottom line are sufficiently simple to define a single research project or monitoring protocol. The process could be continued further to detail parts of protocols, such as individual sampling procedures, but then the detail of the plan obscures the relationships of actions and goals for the entire *vital signs* program and loses its educational effectiveness (Davis *et al.* 1994).

The second tier on the step-down diagram indicates that the program could achieve the four goals identified above if, and only if, it:

- developed a conceptual model of park ecosystems,
- conducted design studies to develop monitoring protocols for environmental vital signs, and
- monitored ecosystem health.

In outline form, the remaining steps, below the program goals are:

1. Develop a conceptual ecosystem model
    - 1.1 Set limits (boundaries) on systems to monitor
    - 1.2 Inventory natural resources
    - 1.3 Review literature for resources occurrence and distribution
    - 1.4 Conduct field surveys for inadequately known taxa
    - 1.5 Make an exhaustive list of mutually exclusive components of the system
    - 1.6 Define biogeographic units, e.g., watersheds, islands, ocean currents, and consider a variety of scales of time and space
    - 1.7 Determine appropriate taxonomic divisions, e.g., fish, invertebrates, kelp
    - 1.8 Identify relationships among system components
2. Conduct design studies to develop monitoring protocols for ecosystem vital signs
    - 2.1 Select critical components from conceptual model to serve as vital signs
        - 2.1.1 Establish selection criteria for taxa, represent all ecological roles, special legal status, endemic, alien, exploited, dominant, common, and charismatic species
        - 2.1.2 Apply criteria to system components identified in conceptual model
    - 2.2 Set component priorities
        - 2.2.1 Review legislation, executive orders, and policies
        - 2.2.2 Consider threats to ecosystems and resources
        - 2.2.3 Review knowledge of each component
        - 2.2.4 Review monitoring technology for each component
        - 2.2.5 Consider other agency responsibilities and programs as opportunities for partnerships
    - 2.3 Design monitoring protocols
        - 2.3.1 Review scientific literature
        - 2.3.2 Select component parameters to monitor
        - 2.3.3 Select and test data acquisition systems
        - 2.3.4 Establish information management system
        - 2.3.5 Prepare standardized report forms
        - 2.3.6 Demonstrate protocol efficacy in field tests
3. Monitor system health
    - 3.1 Obtain funding
        - 3.1.1 Market monitoring needs
        - 3.1.2 Establish accountability for resources
        - 3.1.3 Obtain scientific and management review
    - 3.2 Obtain personnel
        - 3.2.1 Determine knowledge and skills required
        - 3.2.2 Prepare organizational plan, with position descriptions and performance standards
        - 3.2.3 Recruit and hire personnel
        - 3.2.4 Establish career ladders and training program
    - 3.3 Implement monitoring protocols
    - 3.4 Synthesize information from monitoring and apply to appropriate issues
        - 3.4.1 Determine historical or nominal values for monitored parameters
        - 3.4.2 Compare current and historical values
        - 3.4.3 Examine values and variations for correlated patterns in space and time with other components, events, and threats

Channel Islands National Park *Vital Signs* Monitoring Program

Conceptual Model

This step-down plan described the design process used to develop a *vital signs* program for Channel Islands National Park. After setting program goals, the next step was to create a conceptual model of the park that all collaborators understood and accepted. The model included the park's biological features, environmental setting, land and sea forms, and threats to the park's ecological integrity, e.g., alien species, unsustainable uses, and pollution. The following description of the park and its environs, combined with the step-down plan, summarizes the conceptual model.

A chain of eight islands, shrouded in fog and surrounded by some the world's largest kelp forests (*Macrocystis pyrifera*), guard the last remnants of America's natural Mediterranean coast. Five of the eight California Channel Islands, and more than 310,000 ha of the surrounding sea bed, are protected by a plethora of conservation designations (Table 1). These islands bridge two biogeographical provinces. In a remarkably small space, they harbor the biologic diversity of 1,500 km of the North American west coast.

The nearby confluence of ocean currents brings nutrients up from the dark sea bed into bright sunlight, building one of the most productive food webs on earth, with more than 1,000 species of marine fish, invertebrates, and algae. Myriad northern elephant seals (*Mirounga angustirostris*), sea lions (*Zalophus* spp.), fur seals (*Callorhinus* spp.), harbor seals (*Phoca* sp.), Cassin's auklets (*Ptychoramphus aleuticus*), Xantus' murrelets (*Endomychura hypolencia*), cormorants (*Phalacrocorax* spp.), pigeon guillemots (*Cepphus columba*), petrels (*Oceanodroma* spp.), gulls (*Larus* spp.), and brown pelicans (*Pelicanus occidentalis*) breed and raise their young on these islands, near abundant food and safe from disturbance on the 240 km meridian of pristine sand beaches, rocky tide pools, and shear cliffs that rings the islands at the sea's edge. Twenty-six kinds of cetaceans cavort around the islands, including vast schools of sleek pacific whitesided dolphins (*Lagenorhynchus obliquidens*), families of acrobatic humpback whales (*Megaptera novaengliae*), swift Orcas (*Orcinus orca*), and the largest animals that ever graced the earth–blue whales (*Sibbaldus musculus*).

A mild mediterranean climate, with short wet winters, long dry summers, and extensive coastal fog, creates a fascinating array of plant and animal communities on the islands. Isolation protects island species from competition with large diverse mainland populations and from destruction by land development. Unique island forms of majestic oaks (*Quercus tomentella*), ironwood (*Lyonothamnus floribundus*), torrey pine (*Pinus torreyana*), and other trees tower above rippling grasslands interspersed with fields of coastal sage (*Artemisia californica* and *Salvia* spp.) and bush lupine (*Lupinus arboreus*). Island wildlife is rich along the riparian corridors of more than a dozen perennial streams that dissect the gently rolling marine terraces marking ancient uplifted shorelines. Small populations and limited island habitats relegate many species to rare and endangered status, and accelerate evolution of unique life forms. Nearly 10% of island plants exist only on these islands today, while fossils record the past presence of giant mice, flightless ducks, and mammoths.

Numerous archeological sites on the islands reveal a rich human culture spanning 100 centuries (10,000 years). Today, the islands sit precariously at the edge of a human tide that threatens to engulf them. Nearly 18 million people live within 300 km. These people bring worldwide demands for coastal resources from some 200 human cultures.

The clear, cool waters of the Pacific both facilitate and limit public access to the islands. Each year, 100,000 SCUBA divers explore island reefs and kelp forests. Boaters find shelter in more than 100 secluded anchorages. Primitive campgrounds provide intrepid visitors intimate views, revealing each island's unique nature. Thousands of day-visitors glimpse island wonders and peek at marine mysteries in tide pools left by the sea's brief daily retreats.

Air and water pollution from nearby metropolitan and industrial developments threaten island ecosystems. Sheep and cattle ranching on the islands introduced other alien species, greatly accelerated erosion, and reduced the height of vegetation from meters to centimeters (thereby further drying the already near-desert islands by virtually eliminating their capacity to capture moisture from the marine fog blown across them by prevailing winds). Island waters used to yield 6,800 tonnes of fish, shellfish, and kelp annually to commercial and recreational fishers, producing 15% of California's nearshore harvest from only 3% of the state's coastal waters. Recent collapses of fishery-targeted populations revealed that managed traditionally, neither the fisheries nor the exploited populations were sustainable. All of these human activities have altered native island communities and collectively threaten their survival. Normal dynamics of these systems mask human influences and make management uncertain, at best.

The conceptual model described briefly above includes biological resources (populations and communities), environmental forces (climate and ocean currents), land forms (islands and ocean basins), and management issues (fisheries, pollution, grazing, alien species, and habitat fragmentation). Specific features of the California Channel Islands ecosystem structure and functioning, combined with management issues, shaped the *vital signs* program by determining what information was needed to address the issues and still maintain the resources unimpaired for the enjoyment of future human generations. A site-specific step-down plan, developed in 1980, was used to identify the system components in a conceptual ecological model, to show the components for which design studies were needed in priority order, and to identify the actions needed to implement a sustained monitoring program in the park (Davis *et al.* 1994).

The *vital signs* program, established in 1981, has endured because it has proven to be a cost-effective way to reduce the uncertainty of management actions by providing reliable information about resources and ecosystem processes. For example, *vital signs* monitoring provided early warnings of collapsing exploited abalone (*Haliotis* spp.) populations and alien plant invasions. The warnings gave resource managers and politicians time to respond before remedial actions became too expensive or impossible to enact, and provided confidence that actions were actually required. V*ital signs* information also guided feral animal eradication programs (rabbits and pigs) by revealing what efforts were most successful and by estimating time and costs required for complete eradication.

Early documented successes also encouraged many people and agencies to participate. The Channel Islands National Park *vital signs* program resulted in a remarkable collaboration of State, Federal, and private interests. The Federal government contributes scientific expertise and management oversight from the Department of the Interior's National Park Service, Geological Survey, Minerals Management Service, and Fish and Wildlife Service, from the Department of Commerce's National Marine Sanctuaries Program and National Marine Fisheries Service, and from the State Department's Man-in-the-Biosphere Program. The State of California contributes university scientists and facilities, Department of Fish and Game biologists and fishery managers, and guidance from regional water quality boards and county air quality boards. Private interests involved in the program include The Nature Conservancy, the Santa Catalina Island Conservancy, and various local groups, such as the Channel Islands Council of Divers, Santa Barbara Museum of Natural History, and Santa Barbara Botanic Garden.

Design Studies

Short-term research studies to develop monitoring protocols were the core design activity. A modified Delphi approach worked well to identify what design studies were needed (Linstone and Turoff 1975). A group of experts on the California Channel Islands shared their individual conceptual models of the park with each other in a workshop and agreed on a generic model. They then used that knowledge to select ecosystem components to monitor, such as sea birds, kelp forest, or terrestrial vegetation, and to decide what parameters could be used as ecological vital signs.

Sub-groups of experts then discussed specific parameters and appropriate spatial and temporal scales for monitoring. For example, to meet *vital signs* goals, plant ecologists decided that island plants needed to be sampled at three spatial scales: individual species' populations, communities, and landscapes, and at respectively increasing time scales of one to five years. It is important to recognize that the *vital signs* design process is an iterative one, and to recognize the limitations of current ecological expertise that approximate a 17^{th} century level of medical knowledge. Consequently, one should acknowledge that the *vital signs* design goal is not to find a final solution in the beginning, but rather to identify a reasonable starting point.

The list of 14 initial design studies (Table 2) identified for the Channel Islands National Park *vital signs* program constituted the skeleton of the collective conceptual model of the park (Davis 1989). Design studies, that each lasted 3-5 years, were conducted for each component and addressed the same five tasks:

1) select index species or factors for this component,
2) develop sampling techniques,
3) test analytical protocols,
4) develop report formats and content, and
5) demonstrate the efficacy of the recommended monitoring protocol by field testing all aspects of the protocol for at least two years.

Selecting species (or other taxa), ecological processes, and the parameters to be measured for each was the first order of business for each design study. This process involved applying six selection criteria to existing inventories (Table 3). The purpose of the criteria was to assure selection of a representative sample of all species in each component and thereby the ecosystem, i.e., to assure that a broad array of ecological roles were represented, including primary producers and high-level consumers, long-lived and short-lived species, sessile filter feeders and mobile grazers and apex predators. The next step was to assure that common and dominant species that characterized communities and provided physical structure were represented. The monitoring program also had to include all endemic, exploited, and alien species as well as all taxa with special legal status, e.g., endangered species. Finally, if all other criteria were equal, we selected heroic, charismatic species with human constituencies, i.e., species about which the public already cares and empathizes.

Table 2. Design studies conducted for the Channel Islands National Park Vital Signs Monitoring program in priority order as determined by the procedure described in section 2.2 of the step-down plan.

Ecosystem Component	Monitoring Protocol Reference	Principal Investigator's Affiliation
Pinnipeds	DeMaster, *et al.* 1984	National Marine Fisheries Service
Information Management	Dye in press	Private Consultant
Tide Pools	Richards and Davis 1993	Private Consultant
Sea Birds	Hunt and Anderson 1988	University of California
Kelp Forests	Davis 1988	National Park Service with California Department of Fish & Game
Land Birds	Van Riper *et al.* 1988	National Park Service
Island Plants & Vegetation	Halvorson et al. 1988	National Park Service
Island Invertebrates	Fellers and Drost 1988a	National Park Service
Island Reptiles & Amphibians	Fellers and Drost 1988b	National Park Service
Island Mammals	Fellers *et al.* 1988	National Park Service
Park Visitors	Davis and Nielsen 1988	National Park Service
Fisheries	Forcucci and Davis 1988	National Park Service
Weather	Halvorson and Doyle 1988	National Park Service
Beaches and Lagoons	Dugan *et al.* 1990	University of California

Table 3. Criteria used to select species, or other taxa, as ecological vital signs for monitoring in Channel Islands National Park, California, and to assure selection of a representative sample of all species and taxa in park ecosystems.

1. Common species that dominate community structure
2. Legal status, e.g., designated endangered species
3. Park or island endemic species
4. Exploited species
5. Alien species (non-native)
6. Heroic, charismatic species with current human constituencies

The next concern was where and when to sample. Site selection began with existing inventories that included distribution maps, e.g. kelp. Where do the species, or other elements, of the component occur? When does reproduction occur (Figure 1)? Monitoring sites need to provide replicate sites within the range of conditions or along gradients. For example, kelp forests in the park occur along two biogeographic and physical gradients. Biogeographically, kelp forest assemblages of algae, invertebrates, and fishes in the cold, nutrient-rich waters of the western islands in the Oregonian zone (that stretches from the park to Alaska) are quite distinct from those in the warm waters around the southeastern islands in the Californian zone (that extends southward from the park to the middle of Baja California in Mexico) and from those in the transition zone between these two extremes. Physically, kelp forests north of the islands are buffeted by winter storms from the Gulf of Alaska, while those on the southern shores are protected from winter storms. The south coast kelp forests are strongly influenced by large summer swells generated from southern hemisphere winter storms and by seasonal upwelling from adjacent oceanic basins. These physical settings create six different kelp forest zones (3 biogeographic zones X 2 physical zones). At least two monitoring sites were established in each of the six zones. Fishing has a major influence on kelp forest structure and function, so additional monitoring sites were selected to compare fished with fishing-free kelp forests, yielding a total of 16 sites (Davis 1988).

Just as a physician puts the thermometer back in the same location in the patient to get reliable results, fixed ecological monitoring sites were identified so that changes in parameters reflected changes over time and not within-site variation. Therefore, each site was carefully marked to assure that sampling occurred in precisely the same place every year.

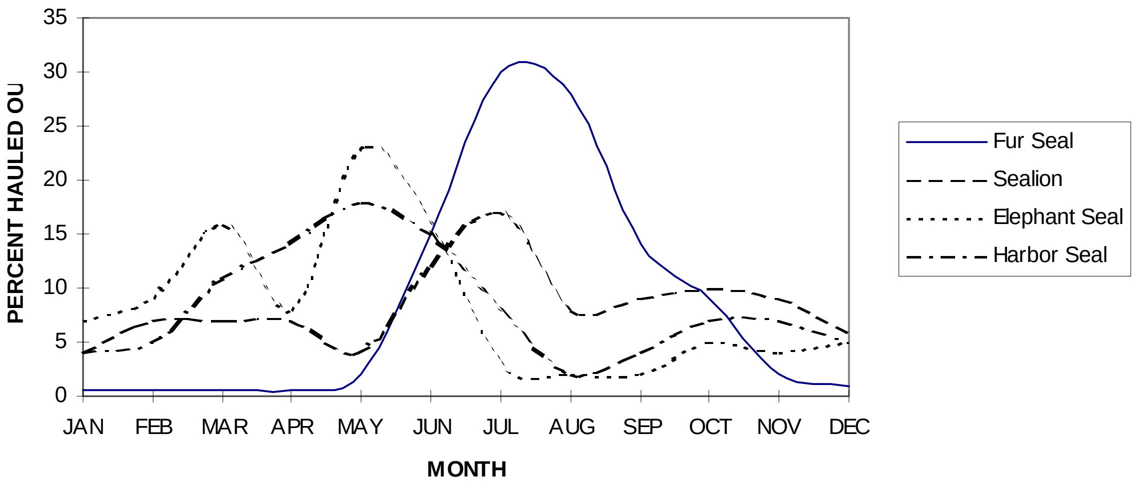

Figure 1. Phenology of pinniped use on rookeries at San Miguel Island in Channel Islands National Park, California: northern fur seal, *Callorhinus ursinus*, California sea lion, *Zalophus californianus*, northern elephant seal, *Mirunga angustirostris*, and harbor seal, *Phoca vitulina*.

Sampling techniques are often species dependent and standard techniques need to be adapted to particular sites and situations. Resolution of these matters was the main function of design studies. Goals for accuracy and precision of monitoring at Channel Islands National Park were set a priori by park managers to detect 40% changes in mean values, with α=0.05 and β=0.20[2]. These guidelines were made explicit by the people who will use the information in political and technical management decisions. These parameters also became important criteria for periodic evaluations of the program.

A variety of sampling techniques was required for each biological component selected for monitoring. More than 1,000 species of plants and animals inhabit kelp forests in the park. The Delphi work group selected 63 taxa to monitor at 16 sites to examine the biological responses to global climate events, such as El Niño, and to differentiate the effects of regional pollution from those of fishing. Abundant, ubiquitous, discrete species (non-colonial) such as sea urchins and giant kelp were relatively easy to count and measure in small quadrats placed in a stratified random fashion around a fixed 100-m long transect line. The design study resolved the minimum number of quadrats needed (20) and how large each needed to be (1-5 m^2) to reduce within-site variation and achieve the established statistical goal (to detect 40% changes in mean values) at all sites. Rarer species that tended to clump, such as abalone and lobster, required larger plot sizes to resolve the same degree of change in abundance. A different sampling strategy based on band-transects (12, 3 m x 20 m) was designed for that purpose.

[2] A type I error (α) means the probability of erroneously reporting that a parameter changed when it really did not, and a type II error (β) means the probability of not detecting a change when it occurs. Probabilities are typically set at 5% and 20%, respectively, because a false report is considered more serious than failing to detect a change.

Another function of design studies was to develop and adapt new technologies to provide the most accurate, precise. and cost-effective techniques. Since colonial species, such as anemones, bryozoans, and algae that literally carpet the bottom cannot be counted easily, 1,000 randomly selected points in 50 plots were used to estimate cover as an index of abundance. Recording observations for 15 taxa at 1,000 points at each site was a significant bookkeeping exercise for divers underwater. SCUBA was the standard equipment used by scientists to access kelp forests, but it required extensive, slow and tedious record keeping underwater by chilled divers to record up to 15,000 observations of bottom cover at each site. Using equipment commonly used in commercial diving that provided air and communications to and from the surface allowed a shift of record keeping activities to warm, dry data recorders at the surface who, by simply recording observations dictated to them by biologist-divers, increased the speed and accuracy of the sampling. Recording bottom cover and abundance of colonial taxa required an average of seven hours at each site using SCUBA. Having divers dictate the observations to a person recording on a ship at the sea surface reduced the average sampling time to 90 minutes. Because the surface recorders were unaffected by cold and nitrogen narcosis that plagued divers, data quality was also measurably improved.

Design studies also needed to invent new techniques and to test old, standard ones. Fish are difficult to sample because they are mobile, patchy, and sensitive to observer presence. We discovered that traditional, non-destructive, *in situ* fish population assessments had very low accuracy (Davis and Anderson 1989). We continue to struggle with appropriate techniques for sampling fishes (Davis *et al.* 1996a) and are currently testing roving-diver and timed-species counts and using the resulting monitoring data to evaluate the techniques.

Implement Monitoring

The detailed monitoring protocols for each component were documented in peer-reviewed handbooks, published in loose-leaf notebook form to facilitate revisions (Davis and Halvorson 1988). Initially (1988), ten handbooks were published for pinnipeds, seabirds, rocky intertidal ecosystems, kelp forests, terrestrial vertebrates (amphibians, reptiles, and mammals), land birds, terrestrial vegetation, fisheries, park visitors, and weather. A protocol for sand beaches and coastal lagoons was added in 1990. The protocols are to be reviewed for design performance and updated at ten-year intervals. The first design review was conducted by an external review panel of statisticians and kelp forest ecologists in 1995. The review panel affirmed the original design criteria and made a few minor suggestions to improve compatibility with other kelp forest studies (Davis *et al.* 1996a). The statisticians on the panel asserted that a prime directive for such programs was to maintain the continuity of the data collection and make only minor changes with ample dual sampling to allow comparisons between original techniques and new 'improved' techniques to assure that calibration and correlation are valid.

Information Management

Information is the primary product of an ecological monitoring program. How it is managed (communicated, archived, and made available) largely determines a program's efficacy, reputation for reliability, and image among critics, peers, and supporters. Each of the 11 peer-reviewed monitoring protocols in the Channel Islands National Park program included directions for data management. In addition to the effort required to collect and record monitoring information, 35-40% of the monitoring program's fiscal and human resources were spent on storing, communicating, and making available the information collected and produced by the vital signs program (Dye in press). The usual, more theoretical, estimates that information management should consume only 10-15 % of the resources of an ecological monitoring program seriously underestimate the effort required in practice (Royal Society of Canada 1995).

Other practical information management lessons learned during development of the Channel Islands *vital signs* program include: 1) using standard, commercially available, software, i.e., avoid custom programs; 2) specifying common fields for all records that relate all databases, e.g., date and location; and 3) planning for and embracing change. Not only were the natural systems that we sought to understand dynamic, the engineered systems we used to manage information were also dynamic. For example, we used 10 generations of software and operating systems in the first 16 years of the Channel Islands program, as we evolved from Apple II microcomputers to Windows-95 and UNIX environments. To describe long-term trends in ecosystem health and to determine normal variation in vital sign parameters, data collected at the beginning of the program must be compatible and comparable with the data collected and stored during the middle and the end of the program. This means that every time a computer operating system changes or the database software changes, the entire database must be converted to the new system. While these changes may be inevitable, the program can be designed to maintain the continuity and compatibility of the information.

Annual reports for each monitoring protocol, e.g., kelp forest or island birds, described current resource conditions, archived annual data, documented monitoring activities varied from year to year, provided end-points for otherwise endless monitoring activities, and documented changes in monitoring protocols. The annual reports were also emotionally important for the monitoring staff and provided opportunities to market the program and its accomplishments within funding agencies, academia, and the general public. Along with annual reports, formal peer-reviews of protocols, operations, and results at 10-year intervals helped to assure program vitality and relevance. During protocol reviews, we re-examined design criteria for accuracy and precision, analyzed data for power to resolve changes, and recommended protocol revisions. This process provided a formal history of program evolution that helped assure data continuity while employing modern technologies and methodologies.

The information generated by *vital signs* monitoring has significantly reduced uncertainty for management decisions and reduced the costs of resolving serious threats to the park's ecological integrity, but the program constituted a significant investment in personnel, infrastructure, and operating funds. Conserving the park, while providing for visitor enjoyment and assuring it is left unimpaired for future generations, requires a team effort by the entire park staff of approximately 60 people. Fewer than 12 of these people dedicated all or part of their time directly to *vital signs* monitoring. The monitoring staff was organized into three working groups: one for marine and coastal resources, one for island resources, and one for information management. Change in staff is inevitable in any long-term program, and should be encouraged in order to keep people excited about their work and growing both professionally and personally. This turnover in staff presented some special problems for maintaining continuity in data collection, archiving, analysis, and reporting because it was difficult to record every significant detail of such complex endeavors. With at least three people in each work group, there was usually one or more experienced person available to train new staff and improve to the operation. We found it difficult to maintain institutional continuity in field operations and data management with fewer than three people in a work group.

Applications of Vital Signs Information to Environmental Issues

Vital signs monitoring was designed to guide and evaluate resource management actions, to provide early warnings of abnormal conditions, to identify possible causes of abnormal conditions, and to help frame research questions to resolve issues. At the California Channel Islands, monitoring has helped control and eliminate invasive alien species, detect and mitigate pollution, recognize unsustainable uses, change fishery management policies, and evaluate population and ecosystem restoration methodologies. A few specific examples are described below.

Frequent and extensive analysis and synthesis of monitoring data facilitated discovery of new features and characteristics of monitored systems. Outbreaks of fatal new diseases, such as withering syndrome in black abalone, *Haliotis cracherodii*, were previously unknown, in part because no rigorous ecological monitoring took place before the *vital signs* program (Richards and Davis 1993). The *vital signs* program revealed not only that black abalone population densities collapsed in the park, but also provided a regional geographic and multi-year temporal description of the spread of excessive mortality. Monitoring characterized the size structure of the surviving abalone population, which exonerated fishing as a proximal cause of the population collapse, and it also defined a density (50% of normal) at which abalone populations ceased to reproduce. These quantitative descriptions directed subsequent research to examine potential infectious agents, rather than toxic pollutants or poaching and other human activities, and led to the discovery of a new species of pathogen (Friedman *et al.* 1995).

The sustained time-series data at landscape scales that *vital signs* programs produce permitted resolution of complex environmental issues too difficult to address with typical ecological studies focused on meter-square plots for one or two seasons (Baskin 1997). Separating the effects of El Niño events, pollution, and fishing on coastal ecosystems so that meaningful political actions could be taken to avoid irreversible resource damage and unnecessary constraints on economic development and exploitation of fishery resources required regional (100s km) analysis over several decades (Davis *et al.* 1996b, 1998).

It is essential that monitoring practitioners publish both positive results and negative efforts. It is important to document both techniques and designs that worked and those that did not in peer-reviewed literature and in topical symposia so others don't have make the same mistakes again. Ecological monitoring is no longer simply a compliance-mandated record of environmental parameters; today it drives explorations at the edge of conservation biology and ecology. As such, its discoveries need to be documented, critiqued and discussed widely. Models of excellence are needed to create and sustain effective *vital signs* programs.

Even before the *vital signs* program began, monitoring wildlife populations in the park provided an early warning of regional pollution with global consequences. Monitoring reproduction and recruitment in California brown pelican rookeries on Anacapa Island identified pesticide (DDT) pollution in the Southern California Bight, and provided sufficient time to ban DDT and restore pelican productivity (Anderson and Gress 1983). More recently, the park's *vital signs* program indicated clearly that DDT was still a problem in coastal ecosystems as evidenced in continued reproductive difficulties experienced by peregrine falcons and bald eagles (Detrich and Garcelon 1986). The *vital signs* program also indicated that progress was being made which thereby encouraged people (society) to continue abatement activities.

The *vital signs* program also helped to decide when human intervention in park ecosystems was appropriate. The Channel Islands National Park rocky intertidal monitoring protocol was modified and applied to Cabrillo National Monument, in San Diego, California in 1989. In 1992, the San Diego municipal sewage treatment effluent discharge pipe broke and dumped 16 billion gallons of treated effluent into the sea less than a kilometer from the monument's monitored tide pools over a two month period. Many people were rightfully concerned about marine life in the tide pools and adjacent kelp forests (Tegner *et al.* 1995). Objective information from pre-spill monitoring established clearly that the effluent had no immediate negative effect on the 15 *vital signs* taxa monitored. In fact, closing the tide pool area to visitation during those two months in order to protect visitors from potential health hazards in the effluent actually relieved trampling and other visitor-related disturbances. Most *vital signs* taxa increased abundance during the spill.

The *vital signs* program in this case saved unnecessary expensive litigation that often occurs without actual knowledge and with a belief that damage is self-evident in such situations. The two month closure associated with the effluent spill constituted a large environmental experiment unlikely to be conducted intentionally. Since the *vital signs* program was in place, it was possible to measure the effects of the event and separate the longer term trends in populations associated with regional environmental events, such as El Niño. For example, the chronic loss of California mussels, *Mytilus californicus*, and feather boa kelp, *Egregia menzesii*, recorded for three years before the effluent spill continued at the same rate during and after the spill, while ground cover of ephemeral algae and sea grass, *Phyllospadix* sp., increased dramatically (Engle and Davis in press).

Many fisheries in California were managed and evaluated largely on the basis of fishery-dependent landings data that were not related to changes in fished populations. Fishery-independent monitoring provided essential corroborative information for fishery managers (Botsford *et al.* 1997). Serial depletion of five species of abalone (*Haliotis* spp.) and then a sea urchin (*Strongylocentrotus franciscanus*) to support a commercial diving fleet was obscured by ambiguous landings data in southern California before monitoring data were available (Dugan and Davis 1993). As a result, fishing exhausted abalone populations before fishery management policies could be changed, and drove at least one species to the verge of extinction (Davis *et al.* 1996b, 1998).

Political systems are frequently frozen into inaction by uncertainty (Wurman 1990). Reliable fishery independent data from vital signs allowed the political process to work by reducing uncertainty regarding abalone population status. The California Fish and Game Commission and State Legislature closed five abalone fisheries to prevent loss of critical brood stock and to facilitate and reduce the costs of rebuilding depleted populations statewide only after vital signs data confirmed imminent abalone population collapses (Figure 2). The abalone population status was implied by declining fishery landings, but contested by fishing interests.

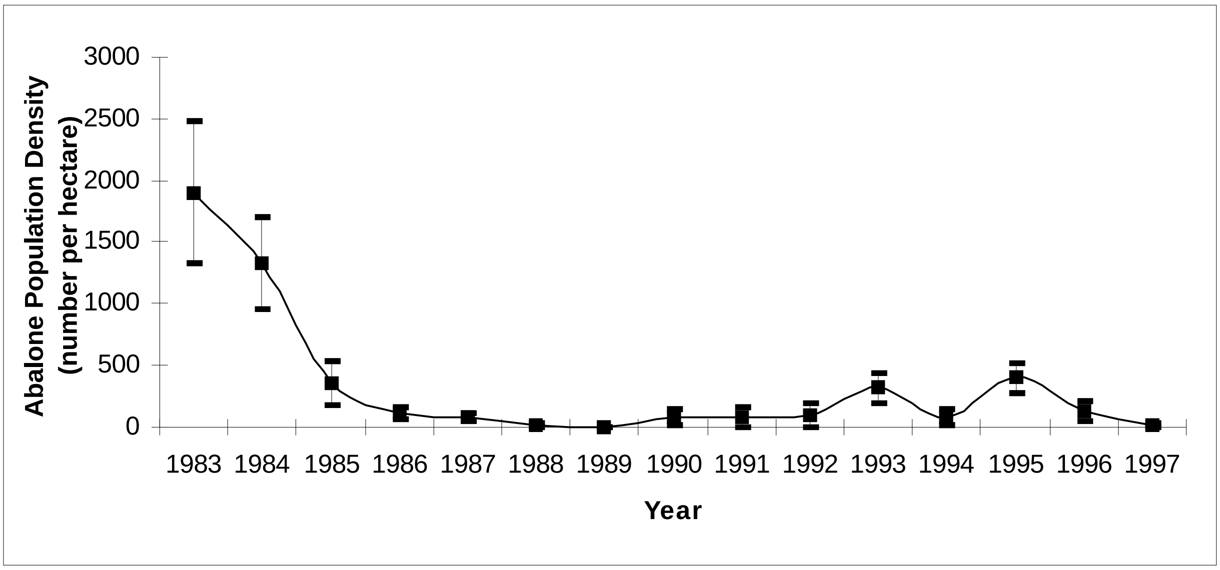

Figure 2. Population densities of red abalone, *Haliotis rufescens*, at Johnson's Lee, Santa Rosa Island, California 1983-1997, mean density ± 1 s. e.

Vital signs monitoring also revealed ecological 'ripple' or 'cascade' effects, beyond the direct effects of fishing on targeted species. As fishing removed large red sea urchins and abalone that competed with smaller unfished purple sea urchins for food and space, purple sea urchin populations in fishing zones increased dramatically, while they remained at historical levels in a small (15 ha) fishing-free reserve at Anacapa Island. Prior to the fishery, and currently in the reserve, red sea urchins generally outnumbered purple sea urchins, but after about a decade of fishing the ratio of purple to red sea urchins leaped to more than 10:1, even though the density of red sea urchins did not change (Fig. 3). Purple sea urchin populations now fluctuate wildly between 10,000 ha^{-1} and 400,000 ha^{-1} in fished areas, while they remain at densities of less than 5,000 ha^{-1} in the fishing-free reserve (Fig. 4). The long-term effects of these abnormally high densities of voracious algal grazers on the dynamics of park kelp forests are unknown, as yet.

Vital signs methodologies were used to test a variety of abalone population restoration techniques at the California Channel Islands (Davis 1995, Davis and Haaker 1995). Ecological monitoring also provided early warning of black abalone (*H. cracherodii)* population collapse (Richards and Davis 1995). The ultimate population collapse was apparently caused by infectious disease in small, dense, but fragmented, populations. Monitoring provided sufficient information, early enough, to protect disease-resistant individuals from fishery harvest and to ensure survival of another generation.

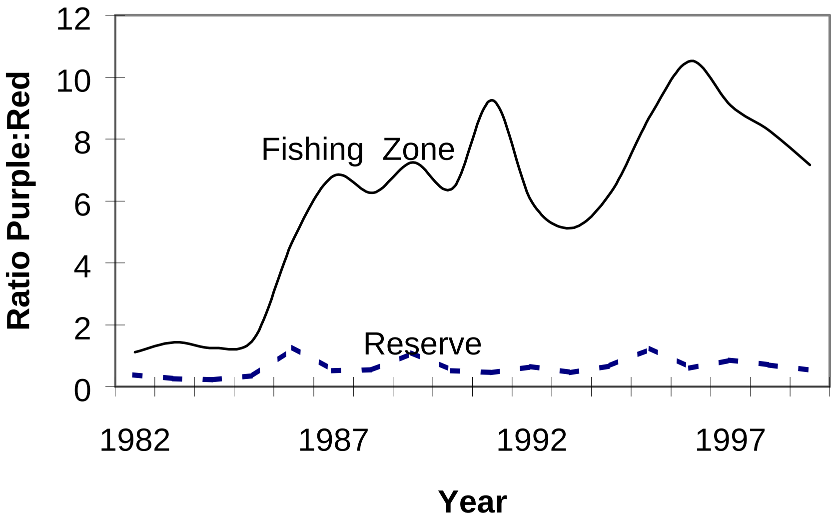

Figure 3. Ratio of purple, *Strongylocentrotus purpuratus,* to red, *S. franciscanus,* sea urchins in a small (15 ha) fishing-free reserve and adjacent fished areas in Channel Islands National Park, California 1982-1998.

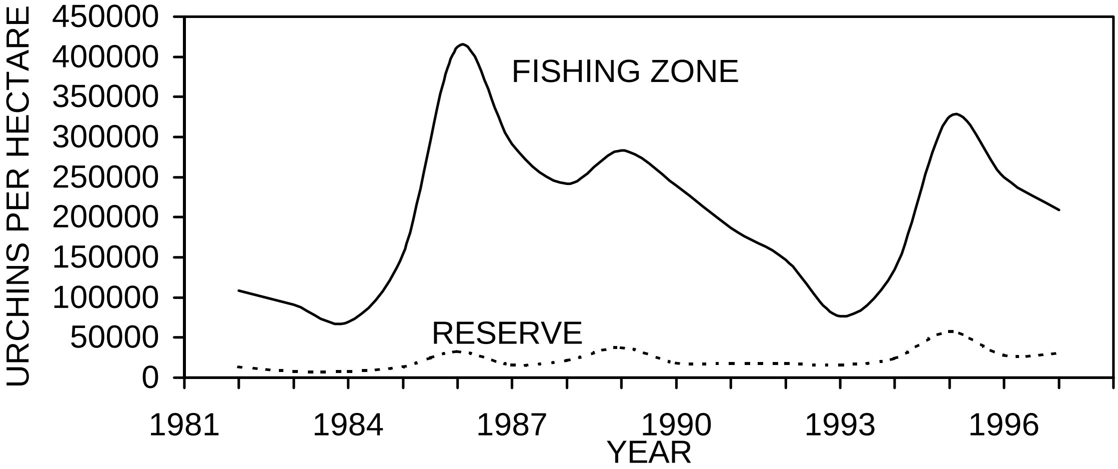

Figure 4. Population densities of purple sea urchins, *Strongylocentrotus purpuratus*, in a small (15 ha) fishing-free reserve and adjacent fished areas in Channel Islands National Park, California 1982-1998.

The Channel Islands National Park *vital signs* program has become a prototype for many other national parks and other agencies, and catalyzed a national *vital signs* program for the U. S. National Park System. The step-down planning process described here has been used successfully in a wide variety of ecological settings with many Delphi-experts, including deserts (Organ Pipe Cactus National Park and Lake Mead National Recreation Area), mountains (Great Basin, Lassen Volcanic and North Cascades National Parks), and the New England coast (Acadia National Park). Other parks emulating the Channel Islands model include Virgin Islands (USVI), Dry Tortugas (FL), Denali (AK), Great Smokey Mountains (TN-NC), Shenendoah (VA), Olympic (WA), a cluster of small prairie parks in the mid-west, and a cluster of parks on the Colorado Plateau. Based on the experience gained in prototype park programs, the National Park Service plans to implement *vital signs* programs in all 250 national park system areas with significant natural resources. Only with the information acquired by *vital signs* programs can national parks be adequately understood, restored, maintained, and protected so that current and future generations can enjoy their wonders, receive their inspiration, and reap the values of their unimpaired ecosystems.

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Long term monitoring program in the Great Barrier Reef marine park

Hugh Sweatman

Australian Institute of Marine Science,
PMB 3 Townsville MC,
Queensland 4810
Australia
h.sweatman@aims.gov.au

Abstract

The AIMS Long Term Monitoring Program is one of a number of initiatives that monitor aspects of the Great Barrier Reef. The objective of the program is to monitor regional status and trends in coral reefs over much of the marine park. This involves a full-time field team that makes annual surveys of 47 reefs chosen to represent three positions across the GBR lagoon at six latitudes.

Benthic organisms are surveyed by videography on five permanently-marked 50 m transects in each of three sites on the NE aspect of each reef. These records are analysed using in-house software to sample 200 points per transect and calculate percent cover values for hierarchically-arranged categories of benthic organisms.

A prescribed set of reef fish species is censused visually on the same transects. The larger, more mobile species are counted on a 5 m wide belt; damselfishes on a 1 m wide belt. The perimeters of core survey reefs plus a number of additional reefs are surveyed by manta tow for crown-of-thorns starfish and cover of living and dead coral on a 10-point scale. The program staff also includes a reef scientist, a biostatistician, a field team manager and a database administrator. Extensive effort is given to quality control including Standard Operating Procedure documents, field calibration of observers, observer comparisons for video analyses, verification of benthic organism identifications, and error trapping and identification of statistically-unlikely data values as they are entered.

Introduction

The Australian Institute of Marine Science (AIMS) was established in the late 1970s. From an early date there has been an emphasis on the collection of long term data sets on coral reef systems. This has been motivated by a sense that such data were conspicuously lacking for coral reefs and that it was appropriate for a government research institution with a core funding base that was not subject to the inter-annual variability of university research grant schemes to invest in such projects. Most long-term projects were intended to look at population dynamics of reef organisms primarily from a scientific interest in ecological processes. An exception was the program of surveys for crown-of-thorns starfish (COTS) *Acanthaster planci,* which was a major bio-political issue in the early 1980s.

The starfish caused dramatic loss of living coral around some tourist destinations such as Green Is near Cairns and provoked talk of the demise of the Great Barrier Reef (GBR). AIMS scientists submitted a proposal to use a federal initiative to combat unemployment, the Commonwealth Employment Program, to fund a large-scale survey of the GBR to establish the scale of the starfish problem. The proposal was accepted and such surveys by AIMS staff then continued as part of a major funding initiative for research on COTS, initially through the GBR Marine Park Authority (GBRMPA), providing information on reef status to the Authority.

Also in the 1980s, AIMS was involved in the ASEAN-Australia Marine Science Project: Living Coastal Resources, a collaboration with ASEAN countries in the development of methods for assessing and monitoring coastal resources. This program involved a number of workshops and conferences and a manual on methods was produced (English et al. 1997).

In 1991, an injection of federal funds allowed the ongoing COTS survey program to be extended in scope to include surveys of benthic organisms and reef fishes. The intention was to build on existing AIMS projects in terms of survey methods and location of sites and to collect data of scientific interest while continuing to provide information relevant to management of the GBR marine park.

Sampling Design

The question

The goals of the program as represented in the original proposal were vague: to assess the ”health” of the GBR. The sampling design that was proposed emphasised “regions”: areas in different positions across the GBR lagoon (inner, mid-shelf, outer shelf) at different latitudes. This encompasses variations in the composition of coral and fish communities (Done 1982, Williams 1982, Williams and Hatcher 1983). These variations are known (Done 1983, Williams 1991) to be greater across the GBR (distances of 50-200 km) than they are along its length (2000 km). While the reefs were not chosen strictly at random, the choices were based more on logistic considerations than biology. The design provides measures of regional status over much of the GBR. What kinds of factors might cause change on a regional scale? Possibilities include:

1. Changes in water quality due to large-scale nutrient inputs affecting larval survival, macro-algal growth, etc.
2. Changes due to large-scale sediment inputs affecting light penetration to corals.
3. Salinity changes due to flood plumes affecting larvae in general as well as corals.
4. COTS
5. Large oil spills
6. Very large or persistent cyclones
7. Coral bleaching

Selection of reefs

The sampling design involves annual surveys of 47 reefs within six latitudinal sectors (Fig. 1). As far as is possible, three reefs have been selected in each of the inshore, mid-shelf and outer shelf "regions" of each sector. In the Capricorn-Bunker sector, there are no adjacent inshore or mid-shelf reefs, so only outer shelf reefs could be included.

Reefs were not selected on the basis of zoning for use, though representatives of all zones are included.

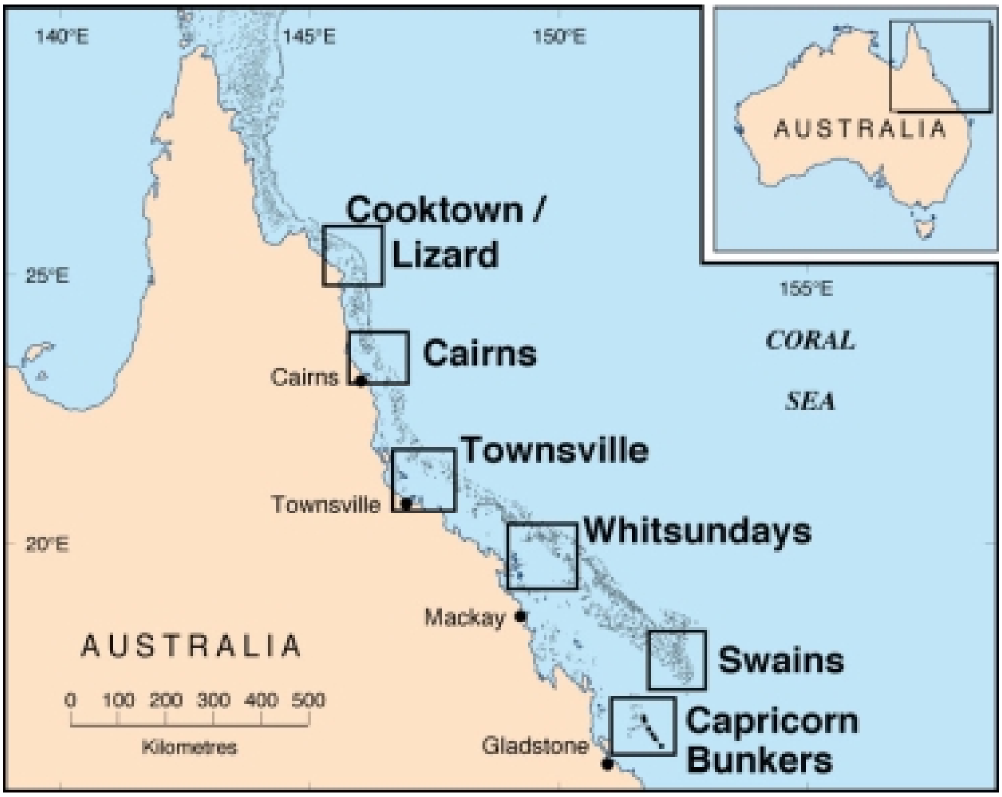
<u>Indicators</u>

When members of the public talk about "an area of good reef" they usually mean that there are lots of fishes and plenty of coral present. For this anthropocentric reason the abundance of reef fishes and the percent cover of various benthic groups were chosen for study. The fish species that were selected did not specifically target the prime commercial species as these tend to be large and to move over wide areas, making it hard to match effective sampling of such fishes to any study of benthic organisms. The surveys of COTS were retained.

Sampling within reefs

The survey reefs are visited once annually in a sequence of five or six cruises over the summer period when the weather is generally better. The cruises visit the sectors in the same order and at the same time each year. Fish and benthic organisms are sampled at three sites in a predetermined habitat on each reef. The chosen habitat is defined as the first stretch of continuous reef with a less than vertical slope that is encountered when following the reef perimeter from the back reef zone towards the front of the reef in a clockwise direction. This habitat is usually situated on the north east flank of the reef. This habitat was chosen because it is relatively distinct and sufficiently sheltered from the prevailing SE tradewinds to allow working in most weather. Sites are separated by 250 m if the area of suitable habitat allows for this degree of spread. If the reef is very small, the sites may extend around the reef to the east and even south-east flanks. There are five 50 m transects within each site. Transects run parallel to the reef crest along the middle of the slope (generally at 6-9 m depth). In the first instance, transects were laid in a haphazard manner over hard substratum with distances of 10-40 m between them. They were then permanently marked with a steel star picket at each end and lengths of reinforcing rod at 10 m intervals.

The use of fixed transects has fundamental implications for analysis of the data. There are obvious logistic costs: steel rods rust and erode and need to be replaced at least every five years. Plastic markers have proved less satisfactory. There is a conflict between the need to relocate sites easily and a desire to avoid visual pollution. However, a study by A.J. Heyward and D.A.J. Ryan (pers. comm.) has found that running transects from points located solely by GPS results in much increased variability through time, since there are both temporal and spatial components. This means that up to five times more samples from such imprecisely located sites are required to allow detection of equivalent change in hard coral cover. Such a figure depends on the characteristics of the organisms that are being studied; this estimate was based on living coral cover in shallow sites on reefs in the northern GBR and at Ningaloo Reef in WA.



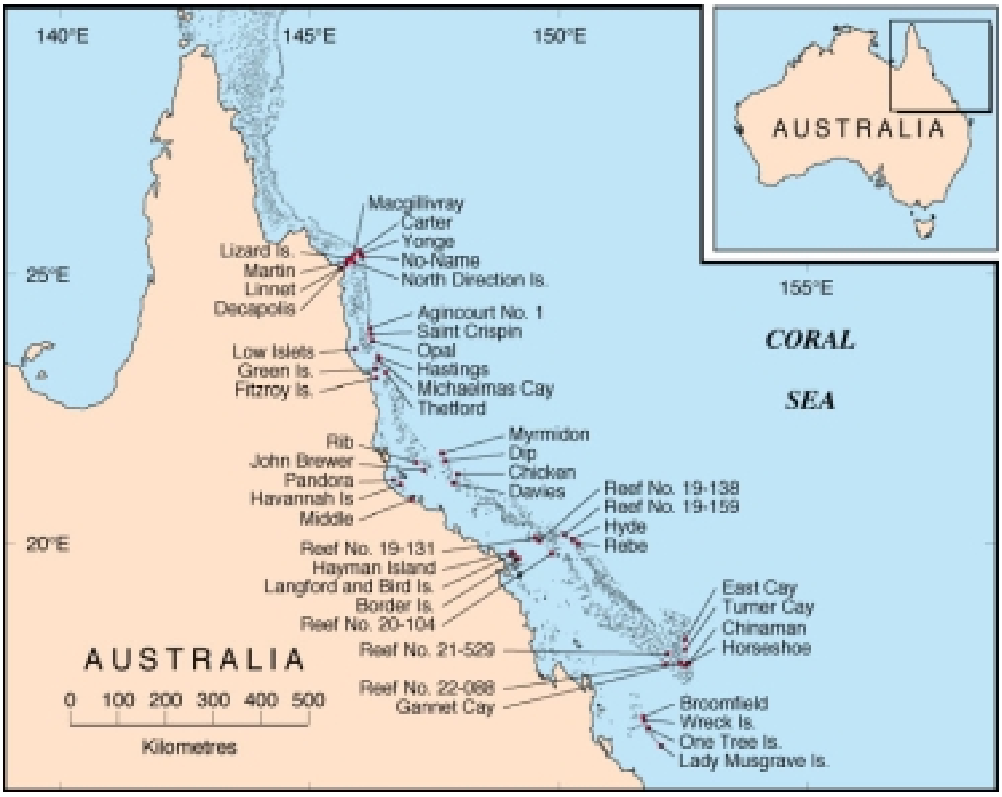


Figure 1. Maps showing (a) the six sectors and (b) the core survey reefs of the AIMS LTMP.

The perimeters of the survey reefs and a variable number (usually about 50) of additional reefs are surveyed by manta tow.

Sampling tasks

Manta Tow

Manta tows provide a broadscale assessment of crown-of-thorns starfish and coral cover around whole reefs. The perimeter of each reef is surveyed using two teams working in opposite directions. A team consists of a boat driver and a snorkeller (observer) who is towed behind the boat on a manta board. At two-minute intervals the boat stops and the observer records the number and size of COTS, number of feeding scars seen, an estimate of living coral cover, dead coral and soft coral on a 10 point scale and underwater visibility. The technique has been scrutinised by Fernandes and others (Fernandes 1990, Fernandes et al. 1990, Moran and De'Ath 1992, Miller and Müller *in press*).

At the completion of manta tow surveys of a reef, incidental observations made during surveys are used to complete a "reef aesthetics" data sheet. This information is designed to provide a broad description of the reef slope, dominant coral type, general aesthetics, giant clam sightings and other phenomena of interest. Details of the technique are given in Bass and Miller (1996).

Quality control

All observers are trained before participating in the broadscale surveys (see Bass and Miller 1996). Field teams attempt to follow manta tow paths marked on aerial photos of survey reefs to standardise the sampling between visits. Estimates of coral cover in particular are influenced by a variety of factors and observers' precision will vary continually (Moran and De'Ath 1992) so on each sampling cruise, selected reefs are towed by two teams following the same path to give a measure of the variability between observers. When observers show signs of bias (see Miller and Müller 1997) they are retrained.

Costs and benefits

The technique clearly sacrifices accuracy and precision for the ability to survey large areas. Underwater visibility also affects resolution.

Fish

Fishes of 191 species are censused visually on the five 50 m transects at each site on each reef. 126 larger more mobile species are counted in a 5 m belt as a surveyor's tape is laid out between the transect markers. Sixty-one species of damselfishes are counted in a 1 m belt on the return swim. Because the field season spans the summer recruitment period, 0+ individuals are omitted from the counts. Full details of the sampling method are given in Halford and Thompson (1996).

Quality control
Observers are trained by comparing precision of identifications and counts with simultaneous counts by experienced observers. All observers are re-calibrated during a field trip run for this purpose before each sampling season. Observers check their estimates of transect width at the end of each transect swim.

Costs and benefits

This procedure requires observers who are experienced in identifying fishes. The circumscribed list of species will bias any estimates of diversity. Estimation of transect width and (particularly) identification of 0+ fishes are potential sources of error. Underwater visibility influences the behaviour of fishes and also affects the precision of the method.

<u>Benthos</u>
A 25 cm wide swathe along each of the 50 m transects is recorded using a Hi-8 video camera held 25-30 cm above the substrate. Percentage cover of corals and other benthic categories are estimated using a point sampling technique, in which approximately 200 systematically-dispersed points are sampled per video transect. To do this, the video player is controlled by software (AIMS Video Transect Analysis System [AVTAS]) that also manages the data entry. Details of the video survey and sampling techniques can be found in Christie *et al*. (1996). Corals were identified to the greatest taxonomic detail achievable using a hierarchical classification (hence *Seriatopora hystrix* is also a “branching coral” and a “hard coral”).

Table 1 Categories of benthic organisms: benthic groups and benthic life-forms

BENTHIC GROUP	BENTHIC LIFE-FORM
Abiotic	
Soft coral	Soft coral
Hard coral	Branching
	Encrusting
	Foliose
	Massive
	Sub-massive
	Solitary mushroom
	Branching *Acropora* spp.
	Tabulate *Acropora* spp.
	Encrusting *Acropora* spp.
	Corymbose *Acropora* spp.
Macro-algae	Macro-algae
	Halimeda spp.
Turf algae	Turf algae
Coralline algae	Coralline algae
Sponge	Sponge
Other	*Millepora* spp.
Indeterminate	

For preliminary analyses, all benthic records are assigned to two different classifications: “benthic groups” and “benthic life-forms” (Table 1). Under “benthic groups,” sample points are categorised into very broad classes of benthic organisms (eg *S. hystrix* = “hard coral”). The “benthic life-forms” scheme is an extension of the “benthic groups” scheme in that the category “hard corals” is subdivided into a number of distinct growth forms (eg “branching coral”).

Quality control

New observers are trained by analysing video records until they achieve concordance with experienced team members. Ongoing inter- and intra-observer comparisons are used to track precision. A program to verify the identification of benthic organisms on the video is also in place. This involves placing colour-coded markers next to benthic organisms whose identity is recorded in the field. These markers appear in the video and the organisms are identified independently, from the image.

Costs and benefits

The video equipment is expensive to buy, is delicate and has significant maintenance costs on top of the cost of tapes. One potential advantage of the medium is that the record can be revisited if necessary, though analogue tapes have a limited storage life. The advent of digital cameras for the amateur market and the rapid evolution of compression techniques and storage media such as digital versatile disks mean that the technological options are changing fast. A significant disadvantage of using video is that, while results of fish counts and manta tow surveys are available at once, it takes a significant time in the laboratory to process the tapes so that percent cover values can be calculated. This is tedious work and extends the minimum reporting time.

One value of video records is their ability to show changes in condition of reefs to the public in a powerful visual way. It would be possible to record panoramas of reef sites routinely for this purpose without using video in the actual sampling.

Table 2: Titles of standard operating procedures. These are available on the AIMS web-page.

Broadscale surveys	Bass DK and Miller IR (1995) Crown-of-thorns starfish and coral surveys using the manta tow and SCUBA search techniques. Standard Operating Procedure No. 1, AIMS, Townsville. 33 pp.
Fishes	Halford AR and Thompson AA (1996) Visual census surveys of reef fish. Standard Operating Procedure No. 3, AIMS, Townsville. 24 pp.
Benthos	Christie CA, Bass DK, Neale SJ, Osborne K and Oxley WG (1996) Surveys of sessile benthic communities using the video technique. Standard Operating Procedure No. 2, AIMS, Townsville. 42 pp.
Data handling	Baker V.J. and Coleman G (in press) A guide to the Reef Monitoring database. Standard Operating Procedure No. 6, AIMS, Townsville.

General quality control

In general, methods and procedures are described in detail in Standard Operating Procedure documents (SOPs, Table 2). These are reviewed about every two years and updated if necessary to accommodate changes in methods or equipment. They provide a guide for new staff, a reference for all and a detailed record of how contemporary data have been collected for future reference.

Database

With the exception of benthic video records, data are entered at sea using data entry programs written for the purpose. These programs include error-trapping routines to check for completeness of records, valid dates and sample ID codes, etc. Data as entered are checked manually against field data sheets. Currently, routines for statistical checking of new data are being implemented. These identify values that are statistically improbable based on the distributions of observations in past surveys. This should help to flag mis-identifications as well as substantial changes.

The data are stored as tables in Oracle running on a Unix system but with the ability to link to MS Access on networked PCs via SQLnet and an ODBC link. The program employs a full time data administrator to develop and refine data checking procedures and methods of access to the database. A SOP (Baker and Coleman, *in press*) will be available soon.

Program power

The seventh annual survey was completed in June 1999. The seven years of surveys provide an estimate of the variance associated with the survey variables and so allow estimates of the power of the program to detect changes in those variables.

How much change is biologically significant?

The objective of the program is to detect long-term changes. Coral reefs are always changing due to natural processes: disturbance by storms, variability in recruitment, etc beside any human impacts. How much change should be considered biologically important? Setting limits to acceptable change is a difficult task and is probably only possible on a case by case basis. For compliance monitoring, GBRMPA used to advocate a flat 20% proportional change in abundance or cover of hard corals, to be detected with 80% probability. In a comprehensive review of long-term studies of tropical coral assemblages, Connell (1997) found that no authors considered ***proportional*** changes in cover of less than 33% to be ecologically significant. The maximum ***absolute*** change in cover in Connell's survey that was not considered significant was 8.8% from 55.2%. Conversely, absolute changes as low as 1.9% (of a total of 5.1% coral cover) was considered ecologically significant. This highlights a practical problem with consideration of ***proportional*** change: a large percentage of a low abundance could be a very small absolute change and consequently be hard to detect.

More recently, Oliver (in press) presented a variable scale for percent cover of hard coral (Fig. 2). Though the numerical values were based on subjective intuition and are open to debate, such a scale does reduce the problems of fixed proportional change.

One issue that has not received much attention is the time scale over which change should be measured. The processes causing change act over different time-scales: a coral cover that takes years to grow may be destroyed in a couple of days by a cyclone; other impacts may be manifest over long periods as long-lived organisms die out without being replaced by recruits. Time-scales are also important for statistical power: a 2% annual increase in coral cover summed over five years will be easier to detect than a 2% change over one year. Logically the interval should be related to the life-span of the organisms and the program's reporting requirements. Here I present power for rates of change over annual intervals and for five year periods.

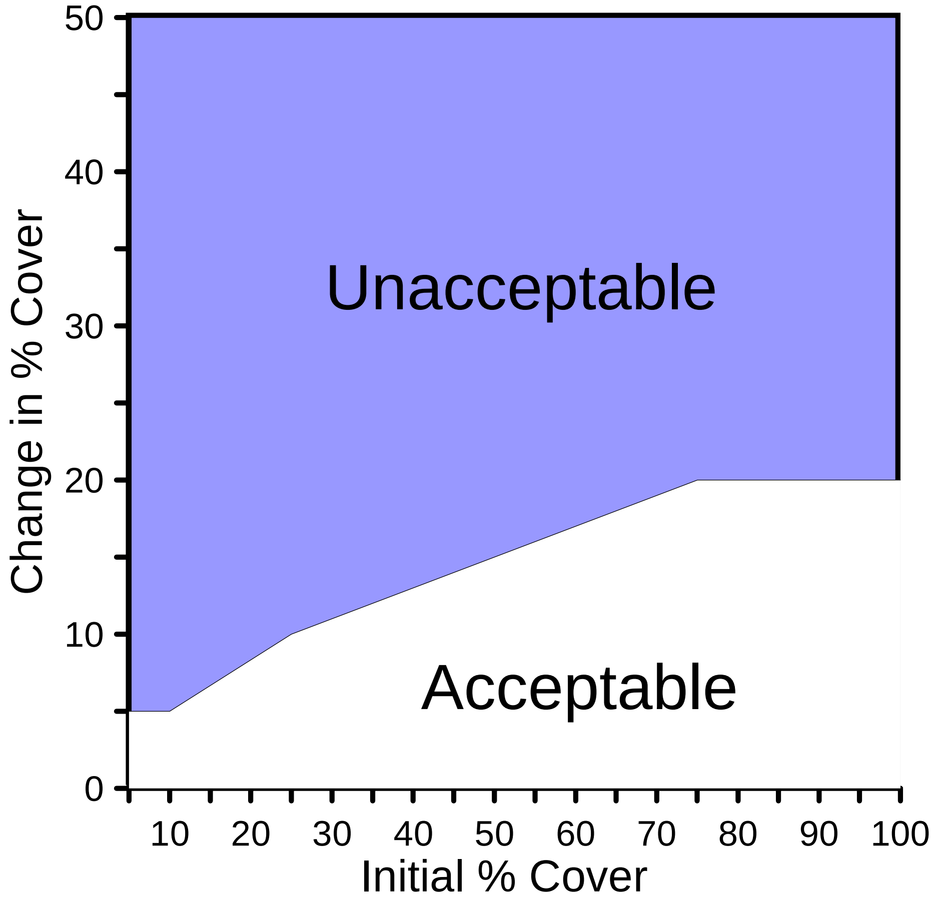


Figure 2. Limits of acceptable change for varying initial values for cover of hard coral. After Oliver (*in press*)

Power of the LTMP to detect changes

Details of statistical analyses and power calculations are given in Appendix 1. One important issue concerns patterns of correlations among repeated measurements of monitoring sites. Traditionally, the error structure of repeated observations on the same sampling unit has been modelled using a compound symmetry, spherical or unstructured error structures. These are the options commonly available in statistical software. However, when the number of observations over time is large relative to the number of observational units, these error structures may not be realistic and in fact may result in inappropriate significant tests. Often in monitoring situations, one would expect observations separated by a short interval to be more similar (and hence more strongly correlated) than observations made a long time apart. Time series error structures may be more appropriate, for example the first order autoregressive (AR(1)) error structure or the autoregressive-moving average (ARMA(1,1)) error structure. These are less readily available in statistical software packages.

The primary objective of the LTMP is the identification of **long term, regional** trends in the health of the reef. The phrase "long term" was defined as trends which occur at a time scale of 5 to 10 years; "regional" refers to one shelf position (inshore, mid-shelf, offshore) in one of the latitudinal sectors.

The following trends were examined:

(1) The current trend in benthic and fish taxa at the **regional level** based upon the last 5 years.

(2) The average trend in benthic and fish taxa which occur at the **regional level** over a period of 5 years

(3) The change in variables of interest that occurred at the **regional level** between the last two annual visits.

These three trends were chosen to provide information on what the populations have been doing in the last 5 years (trend 1), where the populations appear to be headed (trend 2) and has there been an acute change in the population in the last year (trend 3).

Power to detect regional changes in cover of benthic organisms

The surveys measure the abundance of benthic organisms in terms of percent cover. Percentage data need transformation to conform to the assumptions of analysis of variance. The chosen transformation complicates presentation of the results because the degree of change that can be detected depends on the initial cover value. Results are most comprehensively displayed as power curves. Figure 3b shows the minimum detectable differences in mean percentage cover of the “hard coral” benthic group in a region. These are the smallest differences in rate of change that should be detected with 90% certainty. Based on recent surveys, an average reef on the GBR has about 30% cover of hard coral. With the current design based on annual surveys of three reefs per region, the detectable annual change (Trend 3) in mean cover of hard coral for a region containing reefs with average coral cover would be a 6% gain or loss in cover per year (dashed curve in Fig. 3b). This is 20% of the coral present. This value is considerably larger than Oliver’s criterion for significant change.

For comparison, detectable differences are also shown for regional estimates on measures of sustained change over a five-year interval (Trend 1) rather than for annual change (solid line in Fig. 3b). This may be an appropriate time perspective for corals and other long-lived organisms.

Detectable differences for other, less abundant, groups are a greater proportion of the initial cover (Fig. 3). Note that in each case, the five-year average trend is the only one for which the program comes close to detecting significant regional change by Oliver's criterion with any certainty.

Power to detect regional changes in abundance of reef fishes

For reef fishes, change in numbers is expressed on a log scale in Fig 4. Once again, Trend 2 gives the best power in each case. Trends 1 and 3 have similar values and only changes greater than a doubling or halving in numbers regionally is likely to be detected with any certainty. As is to be expected, estimates of abundance of mobile fishes are more variable than estimates of benthic cover, so the proportional changes that can be detected are much greater.

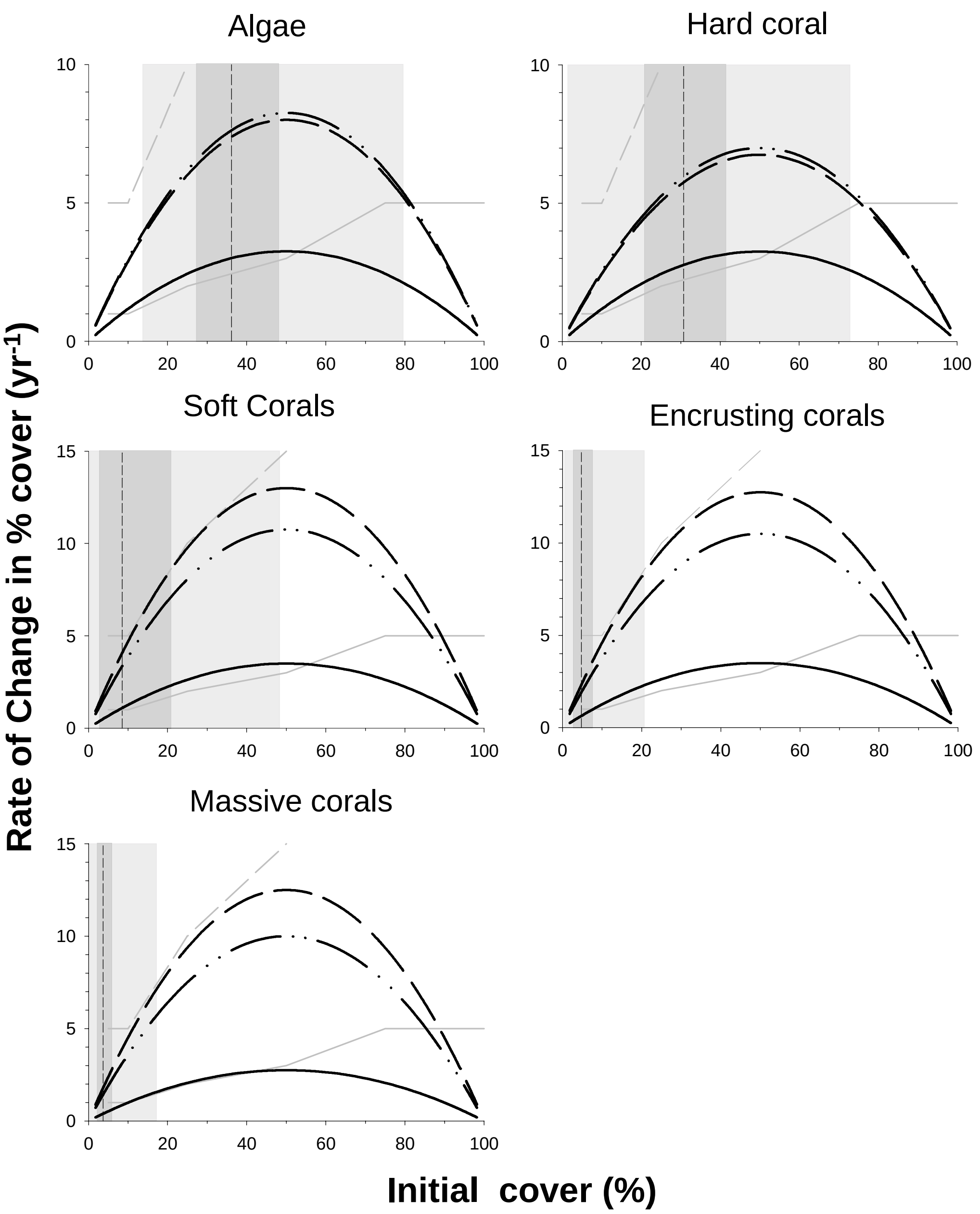


Figure 3. Power graphs showing detectable rates of change in cover of five groups of benthic organisms for different initial values. Solid black line refers to average annual change over 5 years; broken black line: change over one year; dash-dot line: current change estimated on 5 years data. See Appendix 1 for statistical details. Pale shaded area gives the range of cover values observed on reefs in 1998; darker shaded area gives quartiles; vertical broken line is the median value for reefs. Solid grey line: acceptable rate of change (Oliver *in press*) based on annual interval; broken grey line: acceptable rate of annual change accumulated over 5 years.

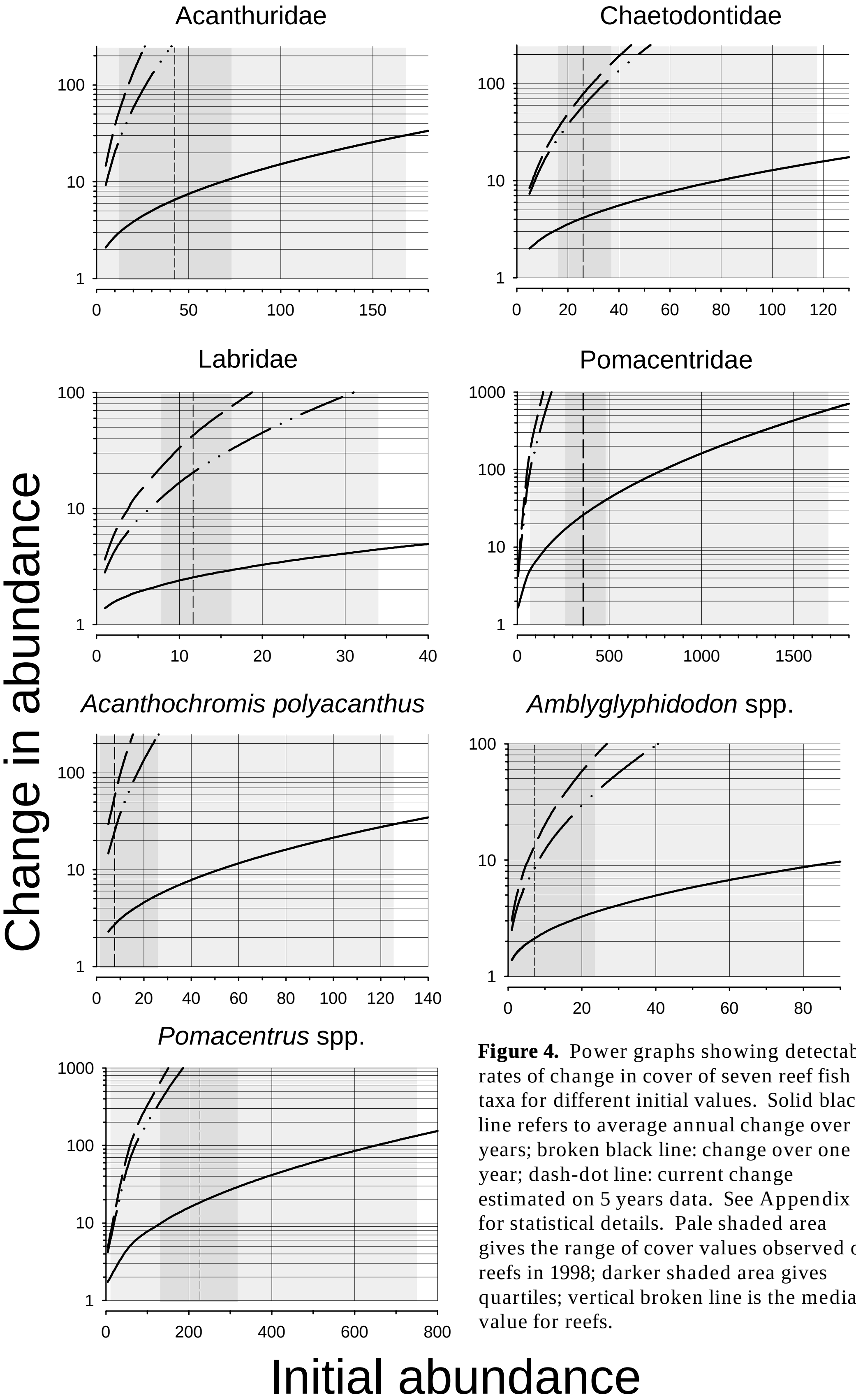


Figure 4. Power graphs showing detectable rates of change in cover of seven reef fish taxa for different initial values. Solid black line refers to average annual change over 5 years; broken black line: change over one year; dash-dot line: current change estimated on 5 years data. See Appendix 1 for statistical details. Pale shaded area gives the range of cover values observed on reefs in 1998; darker shaded area gives quartiles; vertical broken line is the median value for reefs.

Staff structure and logistics

Staff of the program consists of a research scientist (PhD), a biostatistician (PhD), a data administrator, a field team manager and six members of the field team. The field team members spend a large proportion of their time at sea over the summer, but are actively involved in data analysis and reporting during the winter months.

Survey trips are generally about 20 days each. In the 1997-98 field season the surveys plus training and calibration trips used 117 days of ship-time.

Discussion

The AIMS Long-term Monitoring Program is an example of a large scale, long-term coral reef monitoring program using professional staff. Much emphasis is placed on quality control of sampling procedures and of data entry. The program is focussed on regional changes. Initial surveys provided a large-scale description of geographic variation in assemblages of benthic organisms and fishes across much of the GBR as a baseline. Subsequent surveys have provided estimates of background variation and of trends in regional status.

The surveys completed so far provide an adequate basis for estimating the power of the program to detect changes and the changes that can be detected with high probability are quite large. This is partly a consequence of the program's large-scale focus on change in regional values and partly a reflection of background variation. A series of smaller programs each focussing on particular impacts would be likely to be able to detect smaller changes with the same probability. Whatever scale is chosen, it is important that statistical power matches expectations. Consideration of the time scale of change that is biologically important is a part of such expectations. In the GBR, examining change over a five year interval gives reasonable statistical power and corresponds reasonably to the World Heritage Committee's requirement that state parties report on the status of WHAs every six years.

Acknowledgment

All statistical matters are the work of DAJ Ryan.

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Appendix 1

Data Analysis

Benthic Taxa

The average percentage cover of each taxon was calculated for each site by averaging the cover estimates from the 5 transects. This average value was transformed using the empirical logit transformation (McCullagh and Nelder 1989) and the statistical model described above fit using the MIXED procedure in SAS (SAS 1996). Estimates of the autoregressive-moving average error structure were obtained, and used to calculate the minimal detectable level for a given contrast. Since the power calculations depend only upon the design of the study and the error structure, the power calculations were carried out for a standard region. A standard region was defined as a region containing three reefs which were visited each year for seven years. Using this description and the estimated covariance structure, the power for each of the above contrasts was calculated for the current design.

Fish Taxa

The total number of individuals in a given taxa was calculated by summing the number of individuals on each site. This value was then transformed using the log of the summed value plus 1, and the statistical model described above was fit using the MIXED procedure in SAS (SAS 1996). Using estimates of the error structure, power calculations were carried out in the same manner as that described for the benthic taxa.

Statistical model

The data for benthic organisms and fishes were modelled using a mixed linear model:

$$y_{ijklm} = \mu_{ij} + \tau(\mu)_{ijl} + \rho(\mu)_{ijk} + \varepsilon_{ijklm},$$

where y_{ijklm} represents the transformed response; μ_{ij} represents the mean transformed response for sector i and shelf position j; $\tau(\mu)_{ijl}$ represents the mean transformed response for time l, sector i and shelf position j; $\rho(\mu)_{ijk}$ represents the random effect of reef k, sector i and shelf position j; and ε_{ijklm} represents the error term for time l, site m, reef k, sector i and shelf position j.

Estimates of statistical power of sampling designs involving repeated measures depend heavily on the pattern of correlation between the measurements in the series: the error structures. In order to assess the power of this program the observed error structures were compared with three models: compound symmetry (CS), first order auto-regressive (AR(1)) and an auto-regressive moving average (ARMA(1,1)) model. The latter two models seem applicable in the context of monitoring long-lived organisms because they incorporate patterns of decreasing correlation between observations as those observations become more distant in time. Covariance structures for many of the benthic groups came closest to an AR(1) structure while those for the fish groups were better described by CS models. The random reef effects were assumed to be normally distributed with mean zero and variance σ_ρ^2, that the errors were normally distributed with mean zero and followed an ARMA(1,1) error structure within sites, and that the random reef effects were distributed independently of the errors. The ARMA(1,1) covariance structure was used because AR(1) and CS models are special cases of the ARMA(1,1). This model was fit using restricted maximum likelihood methods as implemented in the MIXED procedure found in SAS (SAS 1996).

The primary objective of the LTMP is the identification of **long term, regional** trends in the health of the reef. The phrase "long term" was defined as trends which occur at a time scale of 5 to 10 years; "regional" refers to a specific shelf position in one of the latitudinal sectors.

For these reasons, the following trends were examined:

(1) The current trend in benthic and fish taxa at the **regional level** based upon the last 5 years.

(2) The average trend in benthic and fish taxa which occur at the **regional level** over a period of 5 years

(3) The change in variables of interest in the last 2 years.

These three trends were chosen to provide information on what the populations have been doing in the last 5 years (trend 1), where the populations appear to be headed (trend 2) and has there been an acute change in the population in the last year (trend 3). These were estimated for each region using contrasts (Hocking 1985)

The power of the program to detect the above changes was calculated using the following formula (Zar 1984):

$$mdd = se\left(t_{\frac{\alpha}{2},df} + t_{1-\beta,df}\right),$$

where *mdd* represents the minimal detectable change in the parameter of interest, *se* represents the best estimate of the standard error of the contrast of interest, $t_{\frac{\alpha}{2},df}$ represents the value of the t-distribution with a Type I error rate of α and degrees of freedom *df* and $t_{1-\beta,df}$ represents the value of the t-distribution with a Type II error rate of β. Note that the estimated power depends upon the hypotheses to be tested and the assumed covariance structure, so these estimates of power will be appropriate if the method of analysis does not change and the estimated covariance structure is a reasonable approximation of the actual covariance structure.

Workshop Discussion

Due to difficulties in recording this first session, there is no transcript of the details of the discussion that followed Hugh's presentation. Most of the questions, however, centred on survey methodology and how that related to the power of tests to detect change.

Long-term monitoring of Tasmanian coastal MPA's

Graham J. Edgar and Neville S. Barrett

Tasmanian Aquaculture & Fisheries Institute,
University of Tasmania
PO Box 252-49
Hobart, TAS

graham.edgar@utas.edu.au
neville.barrett@utas.edu.au

This talk today is centred on benefits of long-term monitoring in marine reserves, and particularly the benefits monitoring provides for management and conservation of fishery species and biodiversity. Long-term monitoring also provides an extremely powerful tool for assessing other impacts on the marine environment (Edgar et al., 1997), including the effects of invasive species (such as *Undaria pinnatifida* in Tasmania), climate change and localised impacts such as oil spills that occur within the monitoring area (Edgar & Barrett, 2000). In Tasmania, mean water temperatures off the Tasmanian east coast have increased by ca. 1.5 ^{O}C (Crawford *et al.* 2000), with major resultant ecosystem shifts that are mediated, *inter alia*, by decreasing populations of the giant kelp *Macrocystis pyrifera* and increasing populations of the warm-temperate sea urchin *Centrostephanus rogersii*. A long-term monitoring program provides the best avenue for detecting such patterns.

The current Tasmanian monitoring program commenced in a relatively modest way in March 1992, and has continued with irregular funding and field surveys once or twice each year since. The program involves collecting biotic data from a total of 13 sites within four Tasmanian MPAs and 14 adjacent reference sites external to the MPAs. At the commencement of the study, we were particularly interested in assessing whether creation of Tasmanian reserves affected (i) biodiversity, or (ii) the abundance or size-distribution of commercially-important fishery species, or (iii) whether indirect broad-scale habitat shifts occurred. We thus wanted to obtain data for a variety of biological variables at different spatial scales. Specific factors monitored included (i) fish, macroinvertebrate and plant species richness, (ii) density and mean size of rock lobsters (*Jasus edwardsii*), abalone (*Haliotis rubra*), blue-throated wrasse (*Notolabrus tetricus*), purple wrasse (*Notolabrus fucicola*) and trumpeter (*Latridopsis forsteri*), and (iii) cover of the dominant seaweeds.

Census methods and protocols used to assess effects of MPAs are described in Edgar & Barrett (1997). Briefly, fishes, large invertebrates and macroalgae at each site were visually censused by divers along four replicate 50 m transect lines using techniques appropriate to scales of distribution of these three major biotic groups. Transects were not fixed, as in Gary Davis' Channel Islands surveys, partly because of a lack of resources and because we considered that limited diver time was more profitably spent surveying additional sites rather than bolting permanent lines to the seabed.

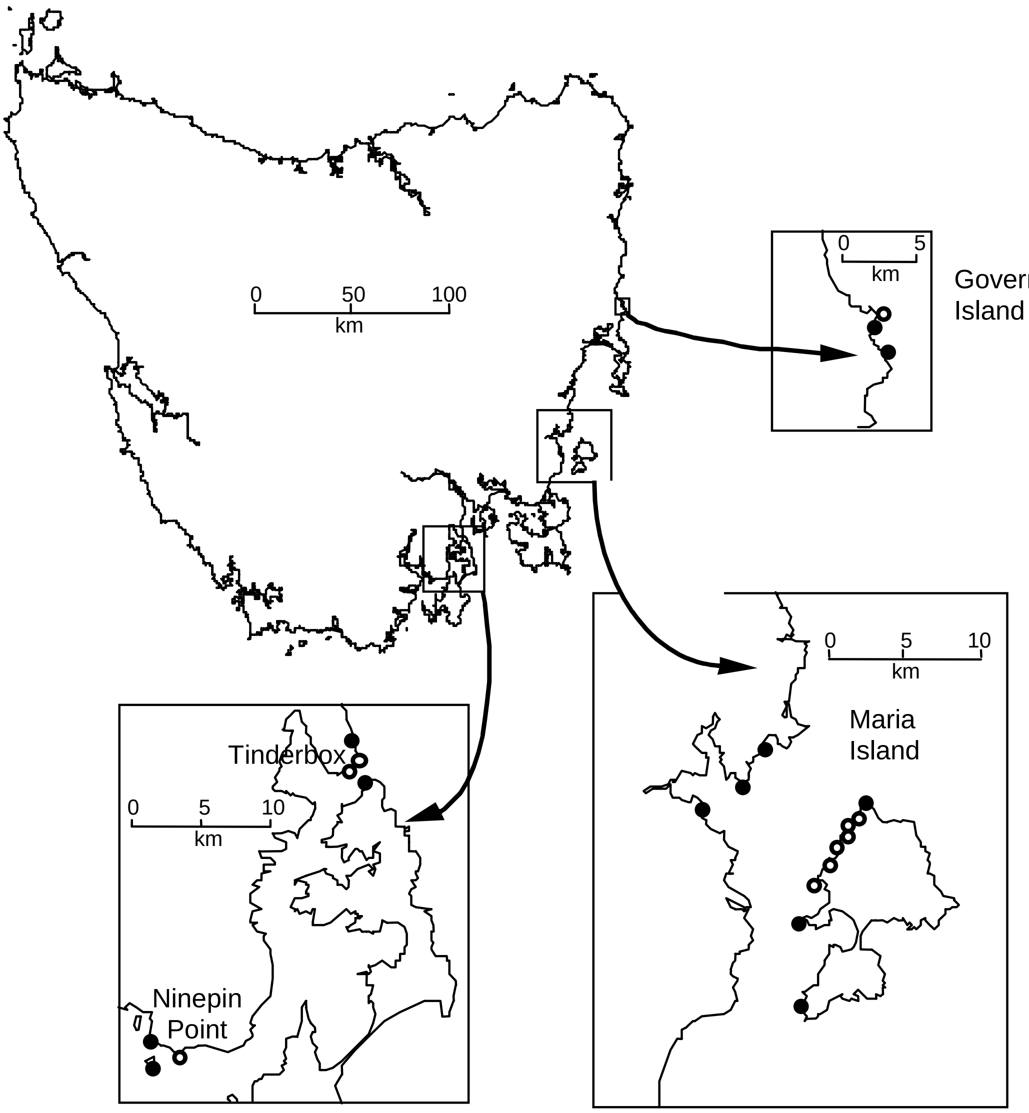

Fig. 1. Map showing distribution of study sites along the eastern Tasmanian coast. Sites with solid circles were located within reserves, open circles indicate external reference sites.

At each reef site, the abundance and size structure of large fishes, the abundance of cryptic fishes and benthic invertebrates, and the percent cover of macroalgae were each censused separately. The densities of large fishes were estimated by laying four 50 m transect lines along the 5 m isobath and recording on waterproof paper the number and estimated size-class of fish within 5 m of each side of the line, as observed by a diver swimming up one side of the line and then back the other. Size-classes used in the study were 25, 50, 75, 100, 125, 150, 200, 250, 300, 350, 375, 400, 500, 625, 750, 875 and 1000+ mm. A total of four 10 m x 50 m transects was thus censused for large fish at each site. The distance between ends of adjacent transects was small (0-5 m) relative to the length of transects (50 m), consequently the four transects at each site were considered subsamples, which indicate variability within the site, rather than as true randomly distributed replicates.

Cryptic fishes and megafaunal invertebrates (large molluscs, echinoderms, crustaceans) were next counted along the transect lines used for the fish survey by recording animals within 1 m of one side of the line (a total of four 1 m x 50 m transects). The distance of 1 m was assessed using a stick carried by the diver. The maximum length of abalone and the carapace length of rock lobsters were measured underwater using vernier callipers whenever possible.

The area covered by different macroalgal species was then quantified by placing a 0.25 m^2 quadrat at 10 m intervals along the transect line and estimating the percent cover of the various plant species. Cover was assessed by counting the number of times each species occurred directly under the 50 positions on the quadrat at which perpendicularly placed wires crossed each other (a total of 1.25 m^2 for each of the 50 m sections of transect line).

Transects were standardised along the 5 m contour to reduce spatial ‘noise’ associated with data, and because (i) this depth strata is heavily targeted by dive, net and pot fishers, (ii) wave turbulence and decompression schedules that constrain SCUBA operations were minimal, and (iii) sand intrusions onto reefs limited the extent of deeper reefal habitat types such that they could not be sampled in all reserves.

Graphical examples of the data generated using these methods are shown in Fig. 2, where data on species richness (number of species per transect) in 1992 and 1997 are presented; Fig. 3, where the mean density of trumpeter in different size-classes in different years is shown; Fig. 4, where data on mean density of rock lobsters in different size-classes in different years are shown; and Fig. 5, where mean cover of common seaweeds is presented (Edgar & Barrett, 1999).

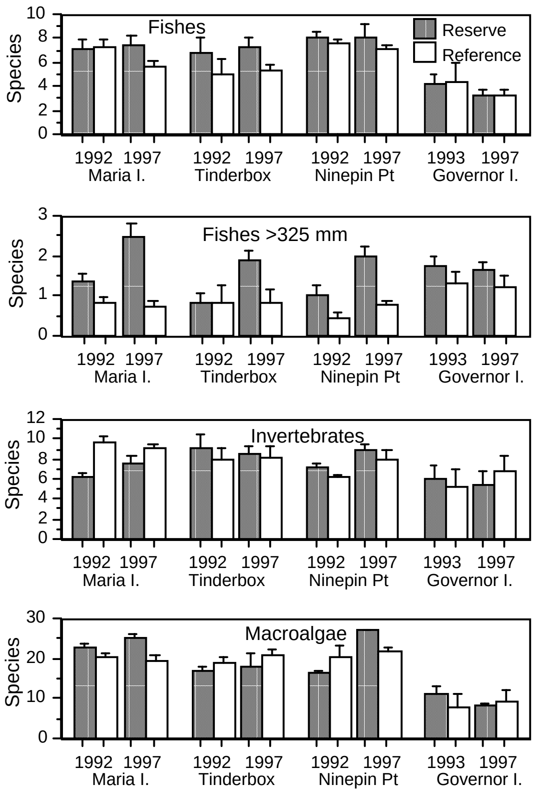

Fig. 2. Mean number of species of fishes, invertebrates and algae recorded per 50 m transect inside and outside reserves in 1992 (1993 at Governor Island) and 1997. Error bars indicate standard error of the means of different sites.

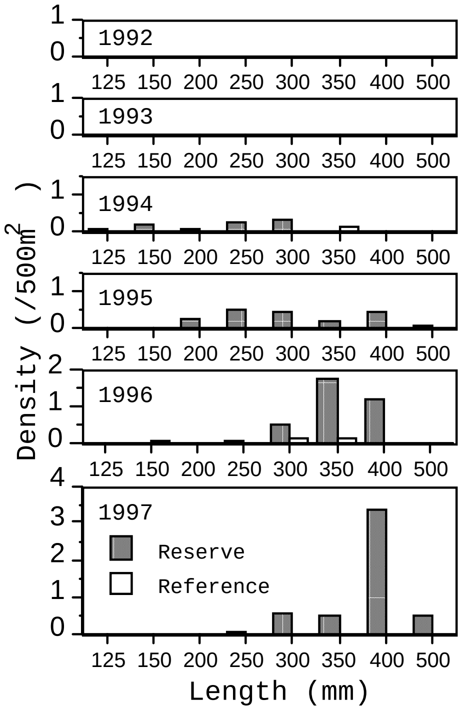

Figure 3. Estimated densities of *Latridopsis forsteri* in different size-classes at Maria Island in different years.

Visual survey techniques, such as those used in this study, have been widely used for estimating fish population sizes on reefs (e.g., Russell 1977), but are affected by a number of biases. The major biases that can affect visual censuses are variability between different divers, underwater visibility, changed behaviour of fishes and habitat variability. These biases will principally affect estimates of fish density and fish size because of the mobility of these animals, but should not greatly affect estimates of plant and slow-moving invertebrate densities (including abalone, rock lobsters and sea urchins).

Sampling biases should not greatly affect conclusions reached in our MPA study because visual estimates were used to indicate relative rather than absolute differences between sites, providing that biases occurred systematically in both reserve and reference locations. For example, the use of different divers on different sampling occasions will add to variability and differences between years but should not greatly affect the most interesting tests of changes (those in reserves relative to those outside, expressed over time), unless one diver was used more for reserve rather than reference sites, or vice versa. It is important in such studies that individual divers are not used disproportionately frequently either inside or outside when censusing reserve sites, and that during censuses one region is not disproportionately sampled during a time of bad weather or poor underwater visibility. Behavioural changes in fishes also need to be considered in MPA studies because fish species that normally avoid divers can modify their behaviour within marine reserves and approach divers (Cole 1994). Such behavioural change can lead to spuriously high density estimates within reserves.

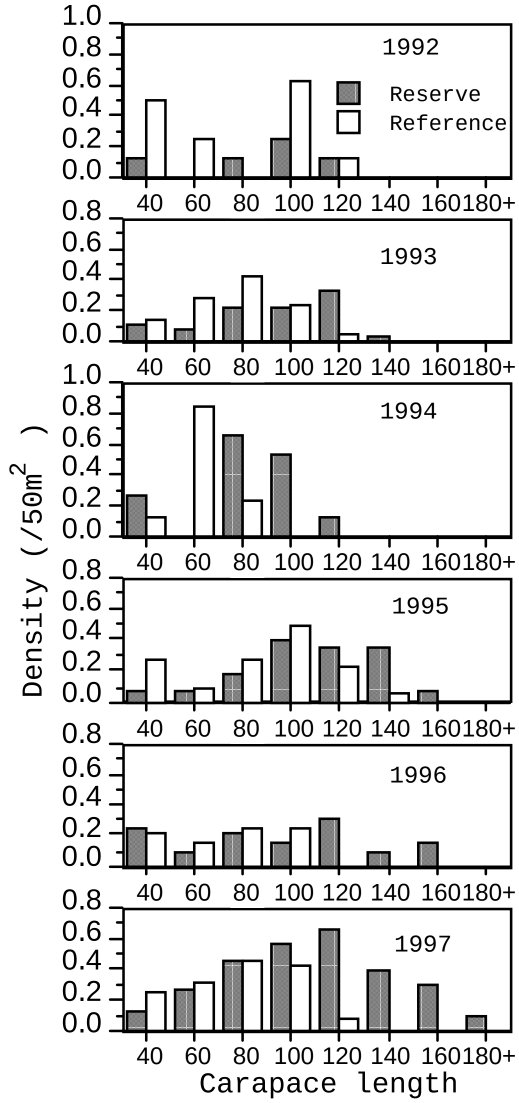

Figure 4. Estimated densities of different size classes of rock lobsters at reserve and external reference sites at Maria Island in the various sampling seasons.

Data collected during our studies have primarily been analysed using an ANOVA-type design, with the specific null hypothesis tested that there are no changes in abundance or mean animal size for different species within the MPA relative to outside following protection. Results of such tests for data from Maria Island are shown in Table 1.

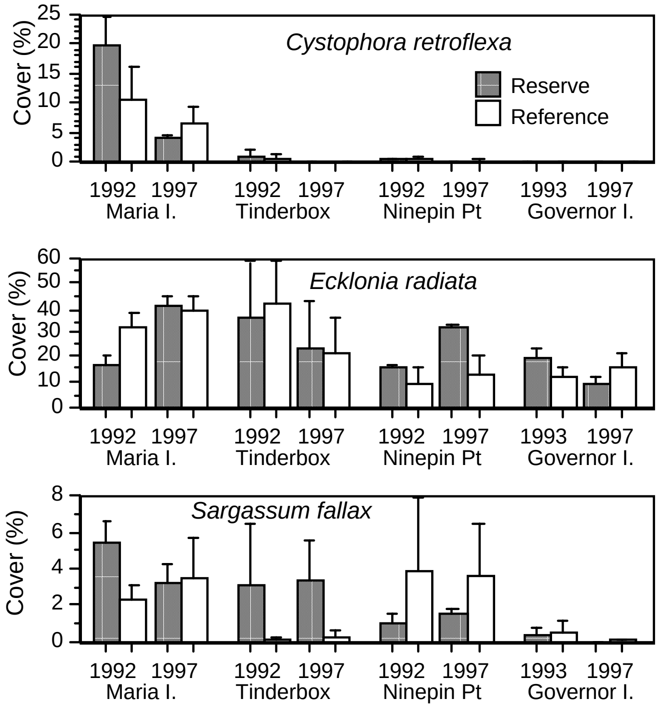

Figure 5. Mean percent cover of common macroalgal species observed along transects within the four marine reserves and at external reference sites in 1992 (1993 at Governor Island) and 1997.

Table 1. Results of two-way ANOVAs (fixed factors: season and reserve) using data on difference in log-transformed total density of large fishes between 1992 and 1997 at Maria Island and Tinderbox, and between 1993 and 1997 at Governor Island. Reserve x season interaction was included as a factor in the models but results were nonsignificant (P>0.10) in all cases so have not been shown. Reserve and season factors both possess one degree of freedom.

	Reserve			Season			Error	
	MS	F	P	MS	F	P	df	MS
Maria Island	0.816	8.251	0.009	0.117	1.185	0.289	20	0.099
Tinderbox	0.287	7.124	0.056	0.044	1.086	0.356	4	0.040
Governor Island	0.000	0.030	0.870	0.547	87.66	0.001	4	0.006

ANOVA designs such as these can provide extremely powerful tests; however, the categorical grouping of data in ANOVA greatly limits its value. All natural communities clearly fluctuate in time and place, hence the null hypothesis tested using ANOVA, that no differences exist between localities, times or interactions, will only be true in artificial or trivial situations. The detection of significant differences between groups of field data using ANOVA indicates that the number of replicates and power of the ANOVA is adequate to detect differences, but provides negligible biological information. The important information is provided by estimates with confidence intervals of the magnitude and direction of differences between groups (Stewart-Oaten, 1995).

Spatial confounding, caused by differences in the separation of reserve and reference sites can also distort results of ANOVA tests. In our study, sites within reserves were separated by distances ranging from 1 to 7 km, while surrounding reference sites were separated by distances of 3 to 21 kilometres. Spatial confounding was unavoidable unless only one internal and one reference site were to be associated with each reserve, a protocol that precludes replication of sites and does not allow effects at individual reserves to be examined. Grouping reference sites together at the same scale of separation as a similar number of reserve sites would lead to much greater confounding because environmental factors may operate differently in the particular region where the reference sites are located. Substantially increasing the number of reference sites to accommodate a 1 km separation between all sites would lead to an unbalanced statistical design with the majority of data collected outside reserves, and would not reduce the separation distance between the most distant reference sites. This type of spatial confounding should be evident in larger confidence intervals for reference sites than for reserve sites because reference sites are further apart and subjected to more variable influences.

A related problem is the error introduced by conducting tests based on a random distribution of samples, when the sampling units used for tests (sites) are selected haphazardly rather than randomly. Ideally, a large set of sampling sites should initially be identified and the particular sites to be sampled then selected using random numbers. In practice, the number of sites available to be sampled is normally very low and the most suitable sites are used. The extent of site confounding may be large in field studies, but generally cannot be estimated. Another aspect of spatial confounding is bias introduced by particular sites possessing disproportionately high density values, and therefore affecting the normality and homogeneity of data. Such biases are generally considered to little affect ANOVA tests (Underwood 1976), although this is often difficult to gauge.

Perhaps the greatest source of interpretative errors in studies with analyses that use ANOVA are Type II errors (i.e. a difference between treatments was present but not detected) that result from low power. A lack of significant differences between groups of field data identified using ANOVA almost certainly indicates that the number of replicates and power of the ANOVA is inadequate to detect differences, rather than that no differences in fact exist.

Regression analyses may well prove more useful than ANOVA for interpreting long-term monitoring data, but have rarely been used in ecological studies within a time-series context. For our data set, curvilinear regression models relating overall change in biological variables with distance from the MPA boundary help illuminate important biological processes (see Fig. 6), such as whether elevated densities of large fishes are available to fishers immediately outside the boundaries of MPAs, and the distance inside MPA boundaries that protection becomes fully effective (and therefore the minimum appropriate size for MPAs to fully protect these species). Combining such spatial models with time-series data should prove an extremely fruitful statistical avenue to explore.

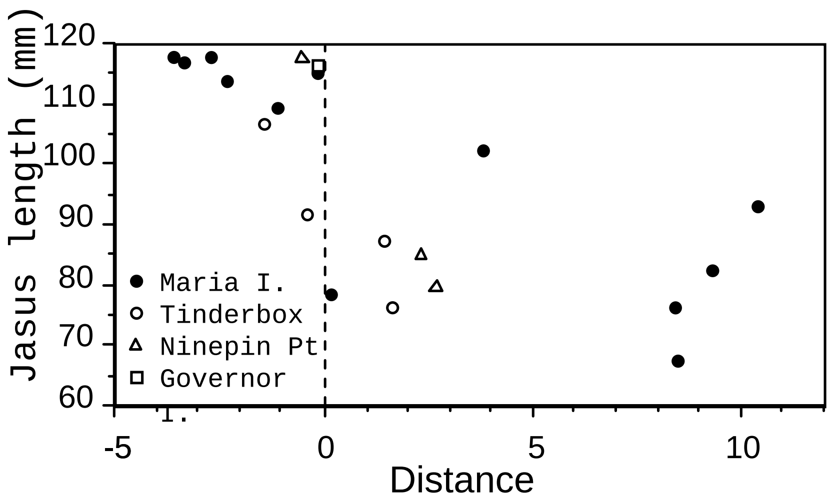

Figure 6. Mean size of rock lobsters at sites versus distance from reserve boundary.

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Workshop Discussion

Graham’s presentation was followed by a short question period. Mick Keough commented on the experimental design in the Tasmanian study, and suggested that where statistical difficulties (using traditional ANOVA designs) had been encountered using the low number of replicate sites at the smaller reserves, results could be better analysed using linear modelling methods. These would use the extensive time-series data generated by this study but ignored in the present analysis, greatly increasing power for detecting changes in the smaller reserves.

Graham commented that Mick’s suggestion was particularly valuable, and showed an overhead detailing the partitioning of variance for fish species richness during the five year study, with variance shown between location, sites, years, seasons, and transects. There was high variance at the 50 m (transect) scale and 50 km (location) scale, but little between sites within locations or between years. He suggested that it was particularly important to repeatedly sample fixed sites, and to incorporate time series into any analysis where possible.

Nick Otway agreed with the importance of using time-series analysis, and suggested the re-partitioning of analysis variance into sub-components would enable you to examine changes in variance in addition to changes in the means.

Romola Stewart asked how would you extrapolate the results of the Tasmanian study to identify fisheries benefits of MPAs. Graham replied that that particular question was the basis of the current FRDC research. At Maria Island, lobster biomass and egg production had increased by an order of magnitude. Some commercial fish species had also increased in abundance and or size (e.g. trumpeter and wrasse), so egg production has increased, but the question we are trying to examine is “How useful is that contribution overall?”

Bernadette O'Neil asked about the trumpeter increase at Maria Island and the significance of the pulse event. Was this a once-off event or due to long-term processes? Graham commented that this pulse of fish at the Maria reserve was the result of climatic influence (pulse events in recruitment) interacting with intense fishing for this species in adjacent fished habitats.

3.4 State and Commonwealth Perspectives - Information requirements, the current status of MPAs and MPA monitoring programs.

This session contained a series of brief contributions from representatives of fisheries and conservation agencies from States with temperate waters as well as a presentation from the Commonwealth. The Commonwealth component was twofold, - firstly, from the broader perspective of the agency guiding the development of the NSRMPA network (Environment Australia), and secondly, from the perspective of monitoring the Commonwealth MPA’s themselves, several of which are located in temperate waters (e.g. Solitary Islands, Commonwealth waters of Jervis Bay, GAB). Apologies were given by Chris Simpson, who was to represent Western Australia, but who had to withdraw at the last moment.

3.4.1 ANZEEC and the performance assessment of MPAs - Bernadette O'Neil.

Bernadette explained the role of Environment Australia and ANZEEC in the funding, development, and co-ordination of the National System of Representative Marine Protected Areas (NRSMPA). ANZEEC had recently produced guidelines for the identification and selection process for the NSRMPA, and had now developed a strategic plan of action, with a performance assessment component. There are 34 actions within the plan, in year one the focus is to define the Comprehensive, Adequate and Representative (CAR) principles underlying the NSRPMA, and to get inter-State agreement on them. This will then set the principles for performance assessment (via monitoring).

Performance assessment will be needed at various levels, national, regional, and site, within the CAR framework. Indicators need to be developed that address information needs, such as identifying vulnerability and threats, and that can be used to check that management outcomes are being achieved. Currently there are meetings between the Commonwealth and States to examine the actions within the strategic plan of action, including performance assessment. Traditional monitoring is driven by science but with no link to management needs, and there is a particular need for more information on performance at the national and state level. Strategic goals have to be identified at the specific MPA level and monitoring at this level needs to identify threats. Current work is therefore developing performance indicators that fit within this broad (national, regional, and site) framework. With respect to funding, the types of work that Environment Australia would be looking at supporting fits within this framework.

Workshop discussion

Colin Buxton - How are we going to fund all this monitoring?

Bernadette commented that Environment Australia knows that there have been problems in the past with ambitious programs being designed and developed, but that have fallen over in a short period of time. Much of the future work should be focussed at the Park level, with performance assessment being built in as a component of park management and therefore funded as a core component of park management. Each state government has that obligation.

Romola Stewart -Is there a program to administer funding for performance assessment?

Bernadette replied that this was not an area tended to be funded by Environment Australia but that they were keen to be involved, with that degree of involvement being determined by the minister. All states felt the Commonwealth had a role in value adding in this area.

3.4.2 Monitoring as a responsibility of the Commonwealth - Nancy Dahl-Tacconi

Nancy discussed the role of the commonwealth in monitoring the commonwealth MPAs, submitting the following paper after the conference.

Current progress in performance assessment of Commonwealth MPAs

Nancy Dahl-Tacconi

Commonwealth Marine Protected Areas Program,
Environment Australia

Introduction

The Commonwealth Marine Protected Areas program focuses on the waters of Australia's Exclusive Economic Zone (EEZ) from three nautical miles to the limits of the EEZ (at generally 200 nautical miles). The primary goals of this program are to establish and manage a comprehensive, adequate and representative system of marine protected areas (MPAs) in Commonwealth waters in order to contribute to the long-term ecological viability of marine ecosystems, to maintain ecological processes and systems, and to protect Australia's biological diversity at all levels (ANZECC TFMPA, 1999). The Commonwealth currently has an estate of eleven MPAs. With the accelerated program of new MPA declarations over the next three years, it is envisaged that there will be some 19 MPAs for which Environment Australia will have management responsibility. The estate comprises a variety of MPAs that range in size from several hectares to several million hectares, in position from in shore areas to remote and deep-sea areas, in location from the north-west to the south-east of Australia's EEZ, and in purpose from no-take to multiple-use. Australia's Oceans Policy provides the overarching planning and management framework for the Commonwealth Marine Protected Areas program. The Policy includes a commitment to develop performance measures for the NRSMPA as well as implementation of monitoring and review measures (Commonwealth of Australia 1998:Vol. 2, page 9). The *Strategic Plan of Action for the National Representative System of Marine Protected Areas* (ANZECC TFMPA, 1999) is a major incentive that is driving performance assessment of Commonwealth MPAs. Through the Strategic Plan of Action for the NRSMPA, each jurisdiction has agreed to develop and implement a performance assessment system for their MPAs, which is consistent with the nationally agreed reporting framework. This framework is based on the *Best Practice in Performance Reporting in Natural Resource Management* (ANZECC WGNPPAM, 1997) and outlined in the *Strategic Plan of Action for the National Representative System of Marine Protected Areas* (ANZECC TFMPA, 1999).

Performance Assessment of Commonwealth MPAs

2.1.1.1 As one of the jurisdictions contributing to the national representative system, the Commonwealth Marine Protected Areas program is committed to developing a performance assessment system for each Commonwealth MPA. The Commonwealth's approach for developing and implementing performance assessment of Commonwealth MPAs focuses on two major areas:

- performance of a marine protected area in adequately protecting its conservation values (outcome based performance), and
- performance of a plan of management in achieving its management objectives (process based performance).

The major purposes of doing performance assessment of each Commonwealth MPA are seen as:

- determining and demonstrating the effectiveness of the MPA in reference to its conservation or other objectives, and
- providing signals/triggers to identify where the management prescriptions need to be altered or remedial action taken in order to achieve conservation or other objectives.

Under the Strategic Plan of Action for the NRSMPA, jurisdictions have agreed to a national performance assessment framework (ANZECC TFMPA, 1999). Outlined below is a practical interpretation of the progress of the Commonwealth jurisdiction in implementing this framework at the individual MPA level. This interpretation suits the type and nature of Commonwealth MPAs and planning and management processes. Other practical interpretations may be better suited to other jurisdictions.

Strategic Objectives and Management Prescriptions

A MPA with clear objectives and relevant management prescriptions has a well defined purpose and can be assessed for its effectiveness. Ideally strategic and specific objectives are derived for each MPA upon declaration. Until recently, objectives of MPAs generally have been determined during the development of the plan of management, which takes place after declaration.

Strategic and specific objectives are now a major component of discussions that take place during the formal consultation process that leads up to the declaration of new Commonwealth MPAs. The consultation process contributes significantly to refining the objectives of a MPA and clarifying management intentions at an early stage of the MPA design process. These objectives are designed to reflect enabling legislation and focus on specific identified conservation values. They also serve as a guide in the process of developing management prescriptions, which form part of the plan of management for each Commonwealth MPA. Management prescriptions are generally aimed at implementing necessary changes and address multiple-use issues where appropriate.

Commonwealth projects currently in this stage of developing strategic and specific objectives include the development of a proposal for the declaration of a Cartier Island Marine Reserve and the development of a joint State/Commonwealth plan of management for the Solitary Islands Marine Park/ Reserve. In each case, the development of objectives is intricately linked with assessing existing information (below).

Assess existing information and determine requirements for more information
To make informed decisions regarding the design of MPAs and management prescriptions for MPAs, current information needs to be collated and the conditions of environmental values assessed. During this process of conservation assessment, major gaps in information are identified and priorities are made for further research. Ideally a synthesis and analysis of existing information would be done prior to the declaration of each MPA so that current information lends itself directly to the objectives, design and zoning of a MPA, but that is not always the case. Sometimes management decisions are overdue by the time a lack of information is identified as a major obstacle. In these cases, rapid assessment techniques need to be explored and interim management decisions considered.

Collecting information on areas within and near Commonwealth MPAs presents some logistical challenges. Commonwealth MPAs are generally remote and also tend to be very large; funding and areas is simply doing an initial survey to provide some indication of what technology tend to limit the timing and extent of access to the areas. A major challenge in making management decisions or designing sampling programs for these large remote is actually there. Generally limited information exists on the natural environment of remote areas and it is often unpublished and residing with a variety of stakeholders. Some opportunities exist to coordinate with users in collecting or acquiring information in remote areas, but ventures to collect this kind of information can still be expensive and technically complicated. Measuring natural trends or human impacts over time and space presents even more financial and technical challenges.

Commonwealth projects currently involving an assessment of existing information include a formal conservation assessment of the natural values around Heard and McDonald Islands, which may lead to a declaration in that area; a survey of current status of conservation values in the area around Ashmore Reef National Nature Reserve, which contribute to the ongoing management of that MPA; and the design of a monitoring program and performance assessment system for the Great Australian Bight Marine Park.

Identification of performance indicators

The Commonwealth has made some progress in developing a transparent process for identifying and selecting performance indicators. The purpose of these indicators, as part of an overall performance assessment system, is to measure the degree to which a MPA is achieving its objectives (outcome indicators) and the degree to which the plan of management is meeting its objectives (process indicators).

An internal workshop was held early in the year to formulate this process. The outcomes of the workshop included a list of criteria that can be conceivably used to select a set of specific performance indicators (measures of environmental parameters or impacts of management actions), which would comprise a performance assessment program. The Commonwealth is interested in further developing this list in consultation with other jurisdictions.

The list of criteria is meant to provide for a complementary and comprehensive set of indicators to effectively assess a variety of objectives (of an MPA or of a management plan). The intention is that all of the criteria should be satisfied if possible and could be satisfied by a set of indicators, rather than by each indicator. An effective set of specific performance indicators should (in no particular order):

– be relevant to MPA objectives (outcomes of the MPA);
– be relevant to management objectives (process of implementing the MPA);
– be cost-effective, simple and practical to implement;
– be meaningful to stakeholders and measurable by lay people;
– be easy to monitor, report on and assess;
– involve spatial and temporal factors (over time, inside and outside an MPA);
– give early warning of potential threats (be sensitive and function as triggers);
– be scientifically credible and statistically robust;
– be interpretable in an unambiguous way;
– be consistent and comparable with those used in other MPAs and jurisdictions;
– be agreed upon through a consultative process involving a large variety of possible indicators;
– foster the cooperative involvement of stakeholders;
– utilise established data sets, methodologies and information collection programs.

The design of a performance assessment program should also include some indication of whether or not the measures being used for the assessment are providing results that can support or trigger management actions – essentially indicators of how good the indicators are. Consultations involving a variety of stakeholders, including scientists, will contribute to this evaluation of the effectiveness and appropriateness of a performance assessment system. A mechanism for reviewing the program, along with management prescriptions, can be built into the regular review of the plan of management for each MPA (every seven years under the *Environment Protection and Biodiversity Conservation Act 1999*).

The Commonwealth is currently working on developing a performance assessment system for the Great Australian Bight Marine Park. This process will include a pilot in which a small set of interim performance indicators will be chosen, mechanisms for involving stakeholders in collecting and reporting information will be trialed and techniques for analyses and feedback will be tested. A more comprehensive performance assessment system will be developed using the criteria mentioned above, input from stakeholder consultations and lessons learned from the pilot.

Design and implementation of monitoring programs

Monitoring programs for Commonwealth MPAs have been extremely varied or ad hoc in the past. Major problems from these programs have been either data that is inappropriate for assessing the objectives of the MPA or difficulties directly comparing information from various sites.

The Commonwealth jurisdiction is aiming to design more strategic monitoring programs in the future, which focus on the objectives and management prescriptions of each MPA. Ideally a research and monitoring program for a MPA will have two main components:

regular monitoring of chosen performance indicators, including environmental measures and measures of the degree to which the MPA is being implemented according to its plan of management; and

'baseline' and ongoing research and monitoring of other environmental parameters, which may contribute to more informed management decisions in the future - including basic surveys to determine abundance and distribution of the diversity of species and identifying natural trends inside and outside a MPA.

The major challenges in developing such monitoring programs will be:

- limited budgets,
- limited access,
- dealing with large spatial and temporal scales,
- development of new technologies (particularly for extensive deep-sea surveying) and
- stakeholder cooperation.

In the development of future monitoring programs for Commonwealth MPAs, the Commonwealth will have two major roles to play. Firstly, the Commonwealth will be involved in identifying and selecting performance indicators for each MPA, which will then guide the design of sampling regimes and structure of monitoring programs for each MPA. Secondly, because Commonwealth MPAs tend to be in remote areas where few stakeholders are present and most users are from industry, the Commonwealth plays an important part in developing cooperative arrangements for involving users of MPAs in collecting and exchanging information. These cooperative arrangements will involve linkages between Commonwealth and industry, Commonwealth and scientists, industry and scientists, and in some cases Australian and international stakeholders.

The Commonwealth jurisdiction is currently in the process of developing such a research and monitoring program for the Great Australian Bight Marine Park in consultation with the South Australian government. This is a cross-jurisdictional arrangement that will help to overcome political boundaries and better achieve an ecosystem-based management and conservation of marine resources.

Reporting and feedback mechanisms

The timing of regular reviews of management plans for each MPA will largely guide the timing and capabilities for reporting and feedback, as these plans can not be changed over a seven year period (as required by the new legislation). Reporting for each MPA should be consistent with requirements for reporting in regional and national systems whenever possible. The first plan of management completed for a Commonwealth MPA after the completion of the Strategic Plan of Action for the NRSMPA was for the Great Australian Bight Marine Park. This plan does not specify the mechanisms for reporting and feedback for performance assessment but indicates that this is an activity that will take place within the first eight months of the plan.

During the development of a research and monitoring program for the Great Australian Bight Marine Park, a mechanism for reporting and feedback will be developed.

Conclusions

The Commonwealth Marine Protected Areas program of Environment Australia has made some progress in implementing a practical framework for designing performance assessment systems for each Commonwealth MPA based on ANZECC best practice guidelines. There has also been considerable progress toward designing a performance assessment system and ongoing research and monitoring program for the Great Australian Bight Marine Park. This will be the first attempt at developing a comprehensive performance assessment system for a Commonwealth MPA and the lessons learned from the process will have implications for other MPAs, in Commonwealth as well as other jurisdictions.

Some major challenges still remain in forming a practical linkage among science, managers and other stakeholders through the development of performance assessment for MPAs. One of these challenges will be achieving a balance that will provide managers with scientifically based support for their decisions while satisfying other stakeholders, including scientists, that the process of applying science for the sake of management is as clear and understandable as possible. Other more logistical challenges will be limited funding, choosing the best available technology and facilitating stakeholder cooperation in managing MPAs.

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3.4.3 New South Wales – Nick Otway and Tim Lynch

Nick Otway gave a brief overview of the MPA process in New South Wales. He explained that there were two organisations involved in MPAs within NSW. These were Fisheries and the National Parks and Wildlife Service, and that the organisations contributed jointly to the Marine Parks Authority, a body that administers the MPAs. There are approximately 70 MPAs in NSW, most of these are aquatic reserves. There are three Marine Parks (Jervis Bay, Lord Howe Island, and the Solitary islands), and NSW is currently working towards an eventual goal of having one in each bioregion.

Currently the existing parks do not have management plans, and these are being developed. Additional protection in NSW waters is provided for individual species protection (eg grey nurse sharks) and habitat protection, so adequacy may be addressed by a combination of this type of protection and aquatic and nature reserves in addition to multiple use Parks. The Marine Parks Authority has a research committee and its objectives are currently related to planning-related research as well as developing performance indicators for future monitoring. This monitoring will include short and long term and spatial components, examining the effects of zoning, and including a modelling component examining the effectiveness of zoning for enhancing fishing. At present the emphasis in on identifying areas suitable for protection under the NSRMPA.

Tim Lynch then outlined some management related monitoring aimed at identifying suitable areas for protection within the Jervis Bay Marine Park.

He submitted the following paper:

NSW Marine Parks: Background, Zoning and Recreational Use

Tim Lynch

Jervis Bay Marine Park project Officer
PO Box 89, Huskisson NSW, 2540

The Jervis Bay Marine Park (JBMP) is one of three recently gazetted marine parks in NSW, the others being the Solitary Islands (SIMP) and, most recently, Lord Howe Marine Park (LHMP) (Figure 1). In the future further marine parks, representative of each marine NSW identified bio-region, may be declared.

JBMP is approximately three hours drive south from Sydney, making it the closest NSW marine park to Australia's major population centers of Sydney, Newcastle and Canberra. The people that live within these cities represent one of the most multicultural populations within Australia. This provides a challenge to biodiversity managers as cultural diversity results in a broad range of taxa being subject to harvest.

The main aims of marine parks in NSW are to:

(a) to conserve marine biological diversity and marine habitats by declaring and providing for the management of a comprehensive system of marine parks,

(b) to maintain ecological processes in marine parks,

(c) where consistent with the preceding objects:

  (i) to provide for ecologically sustainable use of fish (including commercial and recreational fishing) and marine vegetation in marine parks, and

  (ii) to provide opportunities for public appreciation, understanding and enjoyment of marine parks.

In accordance with the requirements of the Marine Parks Act, operational and zoning plans are currently being developed for JBMP and SIMP. Management of marine parks in NSW is based on the concept of multiple use. This means zoning of JBMP will be unlike the strict no-take designs of say Tasmanian, Chilean and New Zealand marine reserves and more like a miniature of the Great Barrier Reef Marine Park model. At 22,000 hectares JBMP provides an intermediate scale between these two designs, with a variety of protection levels within the park boundary. Four zones will be used within the park. The highest level of protection will be granted to no-take zones or sanctuary zones. Three other zones, habitat protection, general use and special purpose will allow for more flexible management prescriptions.

While the base of operational and zoning is ecological, the development of the plans have included a strong consultative process between park staff, the general public and identified stakeholders. As part of the consultation process the public were surveyed in regard to their opinions on the values, uses and conflicts in the park.

After the relatively passive use of the park for swimming and beach activities recreational fishing was the most important use identified by the public (MPA, 1999).

While much is made of monitoring marine biodiversity in marine parks little seems to be mentioned about monitoring people. In global marine systems humans are top predator and have been shown to have community wide structuring roles through top down trophic-cascades (Estes, *et al*., 1998; Castilla, 1999). While log-book supervision by fisheries management organisations allows for the commercial catch to be understood, figures on recreational fishing are much more difficult to obtain and usually require field sampling.

Sampling of recreational fishing distribution and abundance was carried out in JBMP over the peak season of summer 1998-1999. The primarily purpose of this was to provide current patterns of use for the planning process. However, a variety of other medium and long term monitoring outcomes can be sought from this work. First, it provided a pilot study to develop a protocol for ongoing monitoring of recreational fishing in JBMP. It was hoped that the pilot would identify a more rigorous design than that used in a previous long term base line study of recreational fishing effort in Jervis Bay by Willams *et al.* (1993) conducted between 1988-1990.

Second, the data can be used to compare the results of zoning decisions to prior recreational fishing pressure. This will test the hypothesis that no-take areas are placed into sites of low fishing pressure, a marine extension of the well documented terrestrial worthless land theory of reservation design (Pressey 1994), where only unwanted areas are excluded from extractive use.

Third, other questions regarding the expected behaviour of recreational fishers in response to zoning can be tested with this type of approach. For instance, do fishers surround and fish the edges of sanctuary zones and does the creation of sanctuary zones concentrate fishing pressure into areas that were once unused? Finally the survey was a before snapshot of use prior to the possible placement of a marina facility, the feasibility of which is currently being examined by Shoalhaven City Council.

Methods

Use was sampled throughout the peak summer period of 1998-1999 using a modified version of circulating boat survey (Hoenig *et al*. 1993). Using a Global Positioning System (GPS), boats and shore fishers were plotted along with a record of their attributes or fields such as boat size, fishing technique, number of fishers and anchoring status. Each individual plot was then recorded as a row by their fields into an Excel database. This database was then imported into the GIS database Arcview. Data on commercially organised professional diving was ignored as a separate monitoring program, using log books, is being developed.

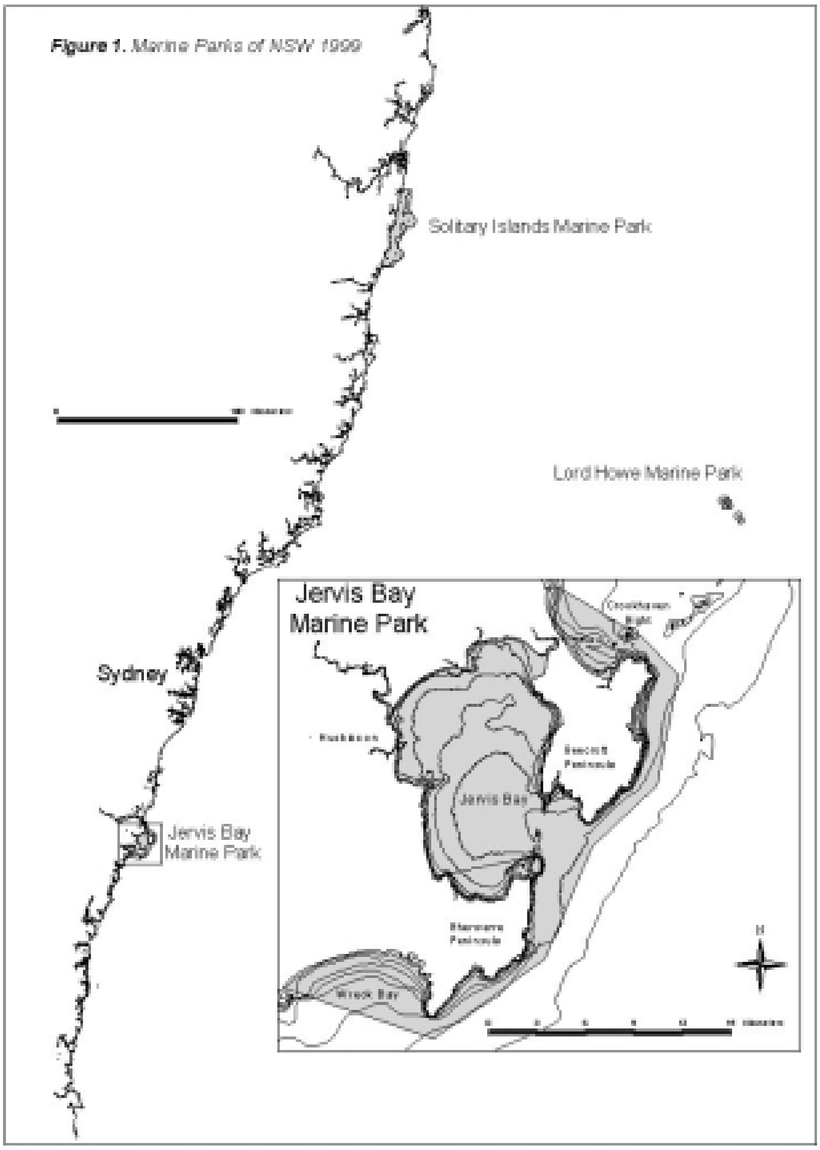
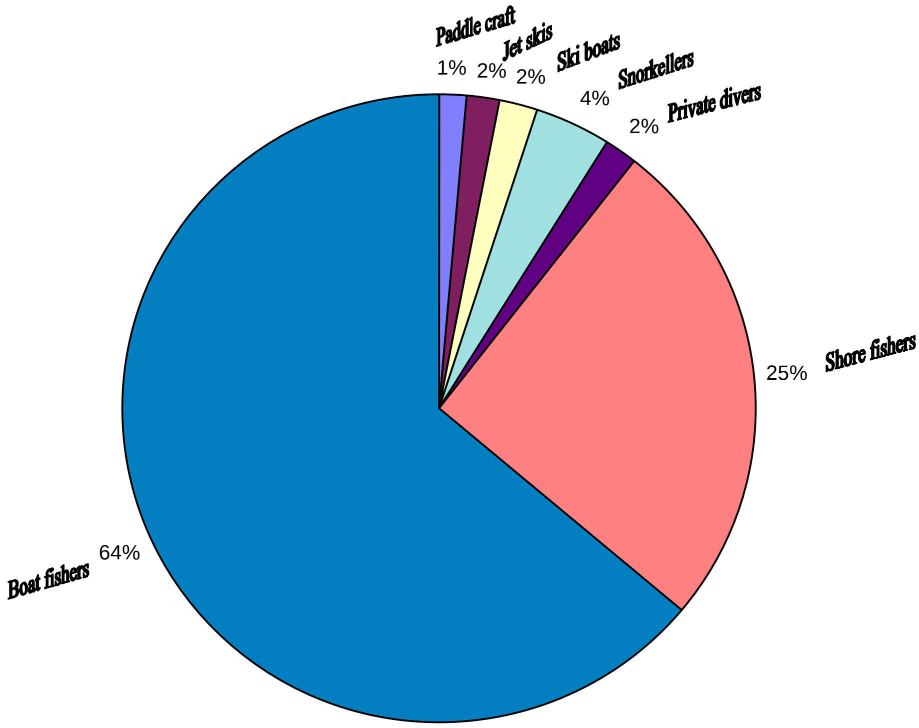


Figure 1. *Marine Parks of NSW 1999*

Figure 2. *Breakdown by use of 2349 people counted within JBMP during summer 1999.*



Results

Recreational fishing was the most common use of small boats in the survey (Figure 2). The boats used were primarily small trailer boat (<6.0m) with also small numbers of intermediate size boat, mostly dive tenders, and larger boats, mostly naval vessels (Figure 3). Trailer boats were generally limited in their distribution to within the confines of Jervis Bay and were concentrated around several relatively shallow submerged reefs and the headlands of the bay (Figure 4).

Discussion

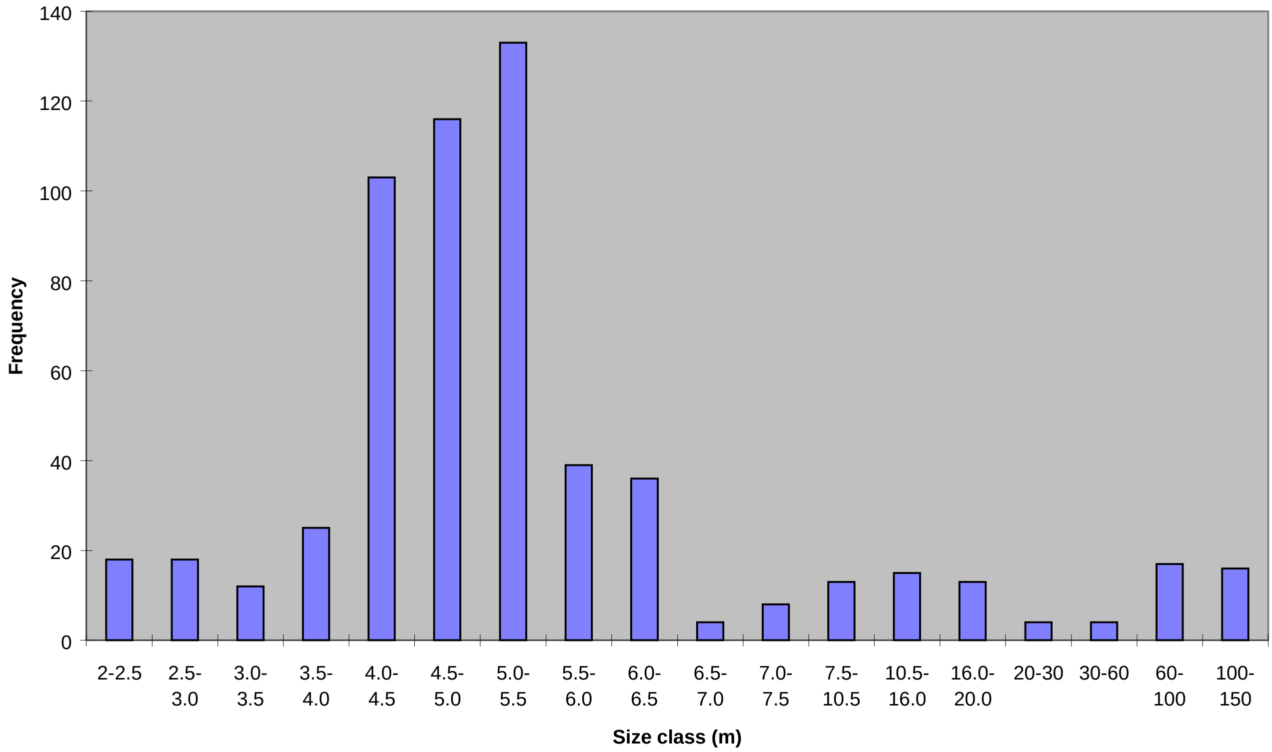
Recreational fishing from small trailer boats dominates the use of small boats within the 1999 peak visitior period sampled in this study. The length of boats was probably limited by the absence of a public marina facility within the bay. This may have also effected the distribution of boats, as larger vessels are needed to operate outside of the bay.

While this technique is still in a development stage the GPS/GIS approach allows for archiving, analysis of both spatial and temporal variability and also the production of easily understandable maps. The communication of the cumulative nature of recreational fishing is one of the challenges to biodiversity managers and scientists.

This technique may help to convince recreational fishers that their sheer weight of numbers may have an effect on biodiversity.

Fishers are sophisticated detectors of habitat and target the most productive areas (Lynch & Bluhdorn, 1997). Fishers can thus be seen as indicators of productive fishing areas and their distribution and abundance can be used to make zoning decisions. In particular recreation fishers target the submerged reefs of Bowen Island, Middle Ground, Bombora Rock, Longnose Point and Boat Harbour.

Figure 3 *JBMP Jan-Feb. 1999 Motor boat size class frequency histogram*



Guidelines for zoning NSW marine parks reflect the complications of decision making in natural resource management. Zoning guidelines state that a representative sample of productive habitat and features essential to ecological processes should be given high protection/protective zoning. However, two other guidelines for zoning NSW MP are that regulation and interference in human activity should be minimised and that high levels of protection are to be given to areas where no removal of natural resources is occurring (MPA. 1999). The relative emphasis given to either of these possibly conflicting groups of guidelines is the balancing act that the consultative process is currently engaged in.

On a technical level zoning that avoids interactions with recreational fishers may have implications for any monitoring program. In particular the sampling designs power to detect change may be influenced by zoning decisions. If areas that are zoned sanctuary are not presently being heavily fished than the treatment of fishing closure may have little measurable effect. It may thus be most cost effective to locate the treatment components of monitoring programs in sanctuary areas that are currently being heavily fished.

Russ *et al*. (1995) expressed these types of concerns in their long-term study of the effects of protective zoning on the coral trout, *Plectropomus leopardus*, a reef fish targeted by both commercial and recreational fishers. Using a 2 replicate ANOVA design to test assumptions regarding fish size, fish age and protection they found no significant differences in these factors even after 6 years of reservation. In the four sites monitored two worked as expected with significant increases in size and age with reservation. However, the other two showed no differences, leading to a net non-significant result. One explanations proposed for this result was that one unreserved site received 2.2 X the fishing effort of the other unreserved replicate.

From a strategic sense marine conservation must try and avoid the trap of only reserving unwanted areas. If a comprehensive and representative approach is to taken and if we are to sell marine protected areas as useful, samples of productive areas must be zoned as sanctuary so that effects of zoning can be demonstrated.

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Workshop discussion

Following the presentation, Graham Edgar commented that at Jervis Bay it looks like sanctuary zones are currently chosen on the basis of least use, but possibly the most important areas to protect are the highest use ones initially as they are the most impacted. Malcolm commented that a big problem in this respect is that the best areas in terms of diversity, abundance etc. are often high use and no one wants to protect them.

Nick suggested that reefs were reefs, and that fishing effort within Jervis Bay was not a reflection of reef quality or suitability but a product of proximity to boat ramps and shelter. Selecting least popular areas for sanctuary zones (no-take) would minimise conflict with fishers.

3.4.4 South Australia – Romola Stewart and Jon Gilliland

The next presentation was from Romola Stewart (EPA) and Jon Gilliland (Primary Industry) from South Australia. Romola indicated that in South Australia at present there was no monitoring program in place at the MPA level, and most survey work had been at the ecosystem level. This work had been focussed on prioritising areas for inclusion in a state component of the NSRMPA. Jon Gilliland explained that there had only been incidental monitoring in the existing reserves, and that had often been more related to fisheries issues, particularly in reserves established for fisheries studies. Some incidental monitoring had also been conducted by community groups in reserves (reefwatch) but nothing was focussed on reserves themselves. A substantial component of future performance assessment of MPAs should focus on the benefits to fisheries, to gain the support of the fishing community for MPAs.

Romola Stewart submitted the following paper:

Information requirements, the current status of MPA's and MPA monitoring programs - a South Australian Perspective

Information requirements

Current Information

South Australian Research and Development Institute (SARDI) Aquatic Sciences recently completed a series of statewide near shore benthic surveys. This information has lead to the identification of marine 'biounits': a classification of ecosystem mapping at the 1-10 km2 scale and provides South Australia with a hierarchical biogeographical classification of coastal marine environments. The study also undertook assessments of conservation values of coastal marine environments, following multivariate analysis of biological data collected from field surveys (marine biodiversity/benthic surveys). These values also used physical and socio-cultural information as criteria in the assessment process.

Requirements

The SARDI report 'Conserving marine biodiversity in South Australia' notes the significant data gaps, particularly biological information, which exist in the offshore, oceanographic regions of South Australia.

There is a further need to capture existing information in a marine biological database, which can be accessed throughout State government. Ideally, this would be established as the central dataset for marine biological data collected by SA Museum, universities and government agencies.
With specific regard to marine parks, the key information requirements of state government are:

- better understanding of the cost benefits of monitoring in marine parks;
- better understanding of the cost benefits of MPA's (particularly for fisheries);
- information on the performance of existing MPA's in South Australia;
- more detailed biological surveys of resources and ecological processes at the individual MPA's level; and
- more detailed biological surveys of high conservation areas identified in the SARDI report for pre-declaration and planning.

Current Status of MPA's

MPA's in South Australia do not reflect a deliberate strategy to capture representative areas of coastal marine and offshore environments for biodiversity conservation. Rather, their development has been opportunistic, with many reflecting a single purpose objective to provide habitat protection for commercial fisheries and rare species, with the remainder largely comprising marine extensions to terrestrial National Parks. As such, many habitats and species assemblages are under-represented within the existing system of MPA's in South Australia

This approach has lead to twenty seven marine protected areas established under the *Fisheries Act 1982*, and another 94 reserves established under the *National Parks and Wildlife Act* (Marine and Estuarine Strategy, 1998). However, most lack a formal management plan, thus making it difficult to measure their effectiveness or their contribution to the protection of marine and coastal ecosystems. The recently established Great Australian Bight Marine Park is the exception and suggests a revised approach to marine protected areas in South Australia.

With the release of the States Marine and Estuarine Strategy in 1998 and the SARDI technical report 'Conserving marine biodiversity in South Australia' (yet to be released), we are now well positioned to progress the establishment of a representative system of marine protected areas. The project 'Identifying candidate areas for a South Australian representative system of MPA's' takes the first step in the selection process. The project will be carried out with high level community and stakeholder participation and lead to a working list of candidate areas for consideration by State Government for MPA declaration.

MPA Monitoring

The creation of marine protected areas in South Australia has generally not led to the establishment of individual park monitoring programs which can detect temporal changes. However, a key information requirement (see above) is to demonstrate the benefits of mpa's as a multiple management tool. Without monitoring programs in place which have the power to associate changes within the reserve to the designated management regime, it is very difficult to determine whether MPA's in South Australia are effective in achieving their management objectives

Whilst there has been some incidental monitoring programs in aquatic reserves, this has largely been focused in areas set-aside for scientific monitoring and through community monitoring programs, such as 'reefwatch'. Whilst these programs make a significant contribution to our knowledge of ecological processes at the individual park level, neither form part of a structured program for park management/performance assessment.

3.4.5 Victoria – Laurie Ferns and Matthew Edmunds

Laurie Ferns submitted the following paper on his component of the presentation:

An Ecological Management Basis for Performance Assessment of Victorian Marine Protected Areas

Lawrance Ferns

Parks, Flora and Fauna Division
Department of Natural Resources and Environment
Victoria. PO Box 500, East Melbourne, VIC 3002, Australia

Introduction

Marine protected areas (MPAs) in Victoria form part of the National Representative System of Marine Protected Areas (NRSMPA) which is being established through cooperation by the Commonwealth, States and Northern Territory. National arrangements for the conservation of marine biodiversity and effective management of marine protected areas (MPAs) have been developed through the *Strategic Plan of Action for the NRSMPA* (ANZECC TFMPA, 1999). This document sets out actions required to achieve the goals of the NRSMPA through bioregional planning[3] and effective management. Key actions of the Plan involve performance assessment which involves development of performance indicators and reporting on outcomes at the individual MPA level, bioregional level and NRSMPA level.

Related to the implementation of performance assessment frameworks outlined in the Strategic Plan of Action for the NRSMPA (ANZECC TFMPA, 1999) is the 'best practice model' developed for the report Best Practice Performance Reporting in Natural Resource Management (ANZECC Working Group on National Parks and Protected Area Management, 1997). The model based on the following criteria:

1. A clear nexus between an agency's legeslative requirements and its strategic objectives for natural resource management;
2. Clearly stated management goals (desired outcomes) that are derived directly from the strategic objectives;
3. A plan of natural resource management programs and activities at both the agency and park level for meeting strategic objectives within a specified time-frame (both medium term and annual);
4. Performance indicators and targets against which the degree to which goals were achieved can be assessed, at both the agency and park level; and

natural resource monitoring programs that provide data for assessment of performance indicators.

[3] The development of bioregions for Australia's marine environment was established through the *Interim Marine and Coastal Regionalisation for Australia* (IMCRA) (Interim Marine and Coastal Regionalisation for Australia Technical Group, 1998).

An important component of the model is the development of approriate perfomance indicators using outcome-based measures, rather than process-based measures. The model stipulates that performance indicators can be applied at any level of management to inform how effective actions are in meeting management objectives. For management at the MPA level, outcome-based measures can be developed through common scientific and monitoring techniques using appropriate standards and rigour. For management at the agency level, outcome-based measures can be developed, for example, for assessing success in implementing statewide programs or change in business activities resulting in greater productivity.

Victoria is committed to the ecological sustainable use of its marine resources through the implementation of management and strategic frameworks that greatly improve the capacity to identify trends in the condition of ecological values and threating processes which impact on those values. *Victoria's Biodiversity Strategy (1997)* provides directions for future management which feature a transparant process of prioity setting for ecological research and monitoring projects which are clearly integrated with management objectives.

Marine performance assessment framework

The Department of Natural Resources and Environment (DNRE) has intiated a trial to assessVictoria's marine biodiversity. MPAs are important component of integrated ecosystem management. Their success in maintaining ecological integrity is based on monitoring appropriate indicators to provide feedback on condition of assets they a designed to protect, and the level of pressure from associated threatening processes both inside and surrounding the MPA.

A adaptive management framework for natural resource management proposed by Walters & Holling (1990) is applied to performance assessment of MPAs. The approach involves:

– gathering of information pertaining to significance and condition of assets;
– identification of threats and their potential impacts; and
– constant examination of historical data to review the adequacy of management actions and subsequent development of adaptive programs.

The approach can be employed as the foundation of a strategic decision support and reporting framework developed for each MPA. Information collated at the MPA level can then be aggregated 'bottom-up' to report at the bioregional and NRSMPA levels. The main components of this reporting framework involve :

– undertaking an assessment of key environmental values for each MPA;
– identifying priority environmental threatening processes which potentially impact on those values;
– assessing the relative success of management actions to ameliorate those threats and recognise any additional or new management actions required;
– undertaking appropriate monitoring strategies which will measure the effectiveness of management addressing those actions and

– developing information systems which will facilitate the storage, retrieval and reporting of monitoring data.

Current Progress

The trial involves establishment of baseline monitoring sites at Port Phillip Heads, Phillip Island, Bunurong and Wilsons Promontory.

Victoria has adopted field methodological and data analysis framework established by Edgar and Barrett (1997) for subtidal rocky reef communities. This approach is employed in Tasmania. The work undertaken at Wilsons Promontory is a joint Victorian – Tasmanian initiative. Transects are measured inter-seasonally (summer and winter or spring and autumn).

The project also integrates 1:100,000 scale habitat stratification of monitored areas to provide management scale resource information.

Activities for 2000

– Complete 2000 inter-seasonal baseline monitoring of above areas.

– Prepare standard reporting frameworks at both the operational and policy / strategic level.

– Develop standard monitoring techniques for other habitats such as seagrass and intertidal areas, and seek to adopt existing national standards where they exist.

– Look to integrate with other related initiatives already undertaken by other marine and terrestrial managers such as mangrove / coastal vegetation monitoring of areas with 'whole of ecosystem' management priorities (eg implementation of Western Port Bay State Environment Protection Policy).

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Following Laurie's presentation, Matthew Edmunds outlined the current monitoring program in Victorian waters.

This program began in 1998 at Port Phillip Heads and involved the use of techniques developed in the Tasmanian monitoring program. With support from NRE, Graham Edgar and Neville Barrett trained Victorian biologists in these techniques, and established an initial baseline. Monitoring at Port Phillip Heads has involved Autumn and Spring surveys in 1998 and 1999. Monitoring sites surveyed by these techniques have also now been established at a number of sites around Phillip Island, with the aim of gaining general information about the health of the Victorian coastal waters at a range of spatial scales.

In 1999, a monitoring program was established at the Bunurong Marine Park. It is planned to also establish a monitoring program at the Wilsons Promontory Marine Park, with the baseline survey being conducted jointly by NRE (Vic) and TAFI (Tas). This assessment work is a mix of MPA and more general monitoring, giving a baseline for the assessment of the health of the Victorian coastline in the long term. At Phillip Island sites were sampled around the coast containing a range of habitat variables and trends in flora and fauna were measured.

The methods used were very similar to those used in the Tasmanian studies giving good general descriptive data for each site. No permanent transects were established, this is an idea that could be examined, but it is the intention to repeat surveys at the same sites rather than use sites randomly allocated. At places such as Port Phillip Heads, establishing sites can be very difficult due to small, shallow, linear reefs, and occasionally surveys need to be at 2 m rather than 5 m due to the lack of availability of suitable reef. Otherwise the techniques used were identical to those used in the Tasmanian study (Matthew described the techniques but they will be discussed in the appendix of these proceedings).

The Victorian work involves trying to establish a baseline that acts as a quantitative inventory of community assemblages and can be used for assessing long term environmental change.

3.4.6 Tasmania – Karen Edyvane and Neville Barrett

Karen Edyvane (Department of Primary Industry, Water and Environment) discussed developments in MPA policy in Tasmania. Within the Tasmanian policy framework, MPAs can be established under two acts, but essentially need the support of both the conservation and fisheries agencies to be effective in giving full protection. Currently most of the existing four marine reserves (no-take MPAs) in Tasmania are very small. Some large reserves are in the pipeline including the State waters surrounding Macquarie Island, the Kent Group of islands in Bass Strait, and in the World Heritage area in Tasmania's Southwest at Port Davey and Bathurst Harbour.

The old policy in Tasmania was to have no-take reserves, in contrast to NSW and the Commonwealth models that have low levels of protection. There is no legislative requirement for monitoring performance of any reserves but the relevant act stated that biodiversity must be conserved, and there is a government commitment in 1990 to stakeholders that the conservation benefits of these areas will be assessed. There has been some monitoring of this conservation benefit undertaken, primarily with funding from Ocean Rescue 2000, and then the Coasts and Clean Seas component of the National Heritage Trust. Monitoring however, needs to not just be at the scale of individual reserves but also at the system level (bioregional scale), using the bioregions developed through the IMCRA process.

In Tasmania a MPA strategy is being developed by the Marine and Marine Industry Council, a ministerial advisory council containing representatives from fishing interests (commercial, recreational and aquaculture), conservation organisations, government departments and the University. This strategy will define an establishment process for MPAs, and outline performance assessment and monitoring guidelines. Issues to consider include entrenching MPA monitoring within each MPAs management plan, and that monitoring be related to the IUCN category of each protected area.

Monitoring should not just be physical and ecological but include endangered species, rare and endemics, reflecting the intent of each area. For example an aim at Macquarie Island would be to monitor the seabirds and marine mammals as key values. Also cultural values in forms such as aesthetics and sustainable use issues need to be examined, and there should be monitoring of key threats and impacts. Monitoring also needs to examine levels of compliance with regulations, the degree of surveillance, and the extent and success of education.

The NSRMPA is to be established on CAR principles (comprehensive, adequate and representative). In this sense adequate means that large enough chunks are protected to be effective, and representative means that all major types of ecosystems are included within each region and across regions. We need mapping and detailed surveys of what is there at the community level to make these decisions. Multivariate analysis of this community data may be good for hypothesis testing, identifying key environmental indicators, and when used to examine mapping information, it may help to identify MPA boundaries. The MPA categories (in terms of IUCN) define the type of monitoring required for performance assessment. This in tern may be undertaken by stakeholders such as reefwatch groups, or by researchers. Community monitoring may be important in some areas.

In Tasmania in the past, research examining the performance of MPAs has focussed on reef communities. In the future, seagrass and kelp forests need to be examined. We need to broadly look at the CAR principles to examine if they are being met. We need to determine whether threatened species and endemics are adequately protected, and if individual MPA boundaries are adequate. The Tasmanian MPA strategy is coming, and will set the strategic direction for future assessment and monitoring.

Neville Barrett provided an outline of the current research. There was to be a brief discussion of the existing Tasmanian monitoring program at this point but it was omitted to save time for further proceedings. Some comments are included here for completeness. With the proclamation of the first Tasmanian marine reserves in September 1991, it was realised that an effective monitoring plan was an essential component of marine reserve policy. The key issues to be addressed included assessing the adequacy of reserves in achieving the intended conservation role, and in providing information for the design of future reserves. One further intention was to adequately document changes such that this information could be used to inform the public of the benefits of MPAs, particularly in areas that the public can relate to (on a local scale).

With funding obtained from Ocean Rescue 2000, and a special allocation from State Cabinet, monitoring began in autumn in 1992 in each of the four new reserves, and at appropriate reference locations. Sampling in the first two years involved both spring and autumn surveys, with this being restricted to only autumn at Maria Island in the following years (94-96), due to a lack of funding. The 94-96 surveys were completed through the University on a shoestring budget.

With a grant from the Environment Australia MPA program and State funds, the sampling was expanded to both seasons in 1997 so that the effects of five years of protection could be examined with season as a factor. In 1998, Maria Island was the only area surveyed, again due to a lack of funds. This year (1999), we have a Coasts and Clean Seas Monitoring program grant that has allowed us to examine all areas in Autumn, and hopefully this funding will continue for 2000 and 2001.

We also now have a FRDC grant (at TAFI) that will allow us to complete some spring surveys to improve our seasonal information, and as this funding is due to continue until mid 2002, will allow us to complete ten years of autumn monitoring in the reserves. Achieving this major milestone will allow us to properly examine changes in these areas over the sort of timeframe that you would reasonably expect to see some substantial changes if they were to arise. It will also give very valuable information on long-term patterns of the stability of reef communities. Obtaining funding for this project has been difficult and involved a wide range of sources, but hopefully the results will demonstrate the value that long term monitoring of key communities can have in understanding the benefits and design constraints of MPAs, and in understanding the dynamics of reef ecosystems. With FRDC funding we are now establishing baselines in additional areas in Tasmania that have been nominated as potential MPAs, and are also helping agencies in other temperate States develop monitoring programs in their proposed MPAs. With NHT Monitoring Program funding, we are transferring monitoring skills to community groups, with the intention of assessing the success of this process, and if it is successful, establishing an ongoing community program in reserves along the lines of Reefwatch in South Australia. In the absence of long term funding, this may be the only way to observe future changes.

4. Session 2. Practical statistical design requirements – Chair: Ass Prof Malcolm Haddon

This session contained a keynote address by Dr Mick Keough from the University of Melbourne. This address was intended to act as a stimulus for the second half of the session, an open discussion on the types and magnitude of biotic change we want to detect, and appropriate sampling designs to achieve that aim. Mick Keough is a well known biologist/statistician, and has a wealth of experience in studying coastal marine ecology, including studies associated with MPAs. The following is a transcript of his presentation.

4.1 Mick Keough – Statistical design requirements.

Mick commented that he had been taking notes on the areas discussed so far, and would expand his talk to incorporate some of these issues. As there is a wide range of interests present, from managers with little statistical training, to field biologists concentrating on specific issues, the talk is as simple as possible, covering a range of suggestions for approaches to experimental design. One question to be addressed is that, as we develop monitoring networks, can we have a broadly based set of protocols with generality? Part of this question is power, which is a very useful concept to highlight our confidence in the results, or our ability to achieve results.

Power can be an informal concept to convey to managers the idea that protocols need to be adequately designed, or it can be the more formal statistical term applied to a particular situation. Some models are often reliable but there are often differences in the concept of what is being modelled. We need to identify a formal statistical model that corresponds to our specific design. Often this model is a formal statistical description of what we are going to do with the data once it is obtained. Having fitted a model we need to decide what management questions it is applying to and what are the magnitudes of change we wish to reliably detect. Power is needed at the design stage to determine our ability to detect a certain critical threshold and ensure replication is sufficient for this.

Coming from a background with a bias towards environmental impact assessments, there are two aspects to most sampling designs. The first is looking for some sort of change in the environment. In the environmental impact literature this is often before/after comparisons, arising primarily from point source impacts. A sudden change in conditions causing immediate response in what we are measuring. However, in the case of MPAs there is a steady change through time following protection so the focus of the existing EI literature is misleading as it is before/after, whereas we really need to pick up change through time.

The second aspect is the comparison of two different management regimes, e.g. protected and unprotected. The environmental impact literature focuses on control/impact situations where there is a point source impact and a sudden change at one point in time. This is usually not the case with MPAs where there may be multiple protected areas, each changing gradually through time, and designs need not be constrained by having a single “impact” site.

In the literature you can identify three families of models that all have a BACI/beyond BACI basis, and most of this literature is focussed on discharge studies and associated methodology. The three families of models have fundamentally different power characteristics and therefore have different ways of impooving power. The first model family is the Stewart-Oaten & Green comparison of control (reference) and impact sites through time. This design examines single control and impact sites only, with obvious constraints on experimental design and interpretation of results more widely. The second family is the Tony Underwood complex, designed to look at impacts over a whole range of spatial and temporal scales.

The third family was developed by Bruce Mapstone and Mick Keough as a part-way model. It places emphasis on the importance of spatial and temporal scales but restrains sampling to scales of management interest. There are other fundamental differences between these models, in addition to the ways of improving power. The characteristics of the Stewart-Oaten design is that it is a simple design with single control/impact sampling before and after. There is an impact at a single site (eg. a point source discharge) and only one control reference. This simple but elegant design looks at divergence at the time of impact, it examines the differences between sites before and the differences after.

The main components then are before, after, control, impact. There may be for example, five visual transects at each site, sufficient for us to get a good estimate of the state of the place at a particular time. The main replication in this design is in the number of times sampled before and after the change. The transects are only used to estimate the mean accurately. The number of sub-samples usually only gives a weak influence on power once a reasonable estimate of the mean is reached. Power is given by the number of times sampled before and after. You can’t usually take more before samples, so you can’t expand power beyond that set initially. This approach has been criticised as a model for wider applications than its initial intent for various reasons, including the limitations of constraining the number of locations.

Another approach is to have multiple control and impact locations, this can be a simple design but it is sometimes difficult as an MPA is not usually replicated. In most cases the question is about the performance of a single MPA, not a series of replicate MPAs. The question is do MPAs diverge from controls? To answer this you can sample through time, every year before the change and every year after. This sampling changes the statistical model underlying the design. The time before and after protection and the replicate visual transects (that estimate accurately the state of location i at time i) don’t appear formally in the analysis. The visual transects are simplified by making them means and this simplifies the statistical models. Where does the power come from then? The simple advice is that the replicates are the locations within each management regime, and these have a direct impact on the power of the program.

The common number of replicate locations in most sampling regimes is two, mostly giving poor power values and if you examine a power function curve even small differences in the number of locations sampled at the bottom of the curve can result in large increases in power. When you do the calculations, in many cases 6-10 locations is usually a reasonable number depending upon the subsamples. Subsamples don't effect power, they just give better estimates of the mean. Once we have enough to characterise a place they have a weak effect on power. The number of times sampled before and after give you the characteristics of what things were like before and after, but multiple years gives better power by removing the vagaries of annual variation-indirect power. The simple advice is to collect enough sub-samples to characterise each site, the more times the better but it is most critical to sample as many locations as possible within the constraints of the sampling program.

Graham Edgar: There are problems selecting control sites when looking for large numbers as there is often not a lot of similar habitats in the near vicinity. Is it best to look at lots of sites and find the best match with the area of interest?

Mick Keough: An increased number of controls gives increasing power but it is true that it is also important how variable the controls are. We really want similar ones but end up choosing worse and worse sites as we use up all the best ones. What that means is that those controls become less similar, and variance in the controls goes up. Increased variance in controls can also decrease power as well. The suggestion of Mapstone and Keough is that you treat it as a function. You order control sites in a series of increasing variation and you can plot the advantages of adding controls against the cost of increased variance. As you add control sites the power function will eventually asymptote and decline.

Graham Edgar: The problem with lots of controls from our data is increased variance.

Mick Keough: This is not necessarily a problem as it is not just the variation between sites that is important but how they each fluctuate through time. They can each be a bit different but if they show similar directions of fluctuations they will work as controls. One of the key points of Stewart-Oaten is that it is the relativities you are looking at not absolute changes. The key thing is the space/time data.

Graham Edgar: It can be very costly to keep adding sites.

Mick Keough: It can be more costly if there is not enough power in the end due to a lack of sites.

Graham Edgar: Management does not see the importance of extra controls.

Mick Keough. You need to characterise the surrounding environment to understand the extent of the impact. It may be important to get management to understand that extra effort may be required in the initial period to sample as many sites as possible, then you can drop the outliers in the later times to improve cost effectiveness.

The other family of methods is that of Underwood's. Most people here are familiar with this design with multiple control and impact locations, and before and after periods. This design is intended to look at impacts at a range of spatial and temporal scales with the assumption that you don't know what impacts you are expecting. This makes it relatively expensive, as you are looking everywhere. It can be cheaper to focus on what scales to look at. One other attribute is that you can not only look at means but also at changes in variability as well. This can change in space and time with protection. For example large fish might be more uniformly spaced and be less variable in MPA's as they become bigger, so you can test for more subtle impacts. The general issue of inside/outside changes can be examined as well.

General issues with this model series include time. In these models time should be random, and this is a point of disagreement with others. Mapstone & Keough suggest you should sample every available season and year before and after. If you accept that, then power calculations are very simple. You just need to take more replicates (locations). If not, then it is much more complicated. In Underwood designs, replicates are not at the next level down. You need to optimise replicates at all levels of scale, and this is very difficult especially for power calculations. It is very difficult to test for impacts in this model because of the complexity of space and time, and you often cannot do the calculations yourself. It is a very expensive design and that is often not affordable in the real world.

There is understandably some confusion in the literature then, regarding power calculations as they differ depending on the statistical model used. You need to be very clear about what model you are going to use and most people need to engage a professional statistician as part of the project team.

One common question is whether there is a standard formula to work out the number of samples or do we need to be flexible in each case, and the answer is the second one. A good example is the studies on recreational harvesting of intertidal shellfish at Williamstown and at Point Nepean in Victoria, where there were areas both open and closed to fishing due to Commonwealth ownership of land. Initially, a single point of time study was conducted at Williamstown. This found, for three of four harvested species, there was significant differences between size and abundance due to protection, whereas there was no difference in unharvested species. This lack of difference with unharvested species was checked with power analysis to examine whether differences would have been detected if present. Subsequently the land reverted to Victorian control and harvesting was allowed. After seven years of harvesting these areas were reassessed (initial sampling was three years before protection was removed). During this time there was a marked decline in two of the harvested species.

A similar question was examined at the Point Nepean location where a similar change of ownership led to a change in protection, this time with species becoming protected. There were similar comparisons of harvested and unharvested species, including examining visitation rates. A sharp contrast was found with the Williamstown study. No differences were found between any of the species examined regardless of their harvest status. It was found that the power of the tests was very low over one year, and that sampling would need to be over five years to get the same power as at Williamstown. The reason is that substantial differences in recruitment patterns exist between the two areas examined, with recruitment being highly variable on the open coast, in both space and time. Patterns were very noisy and so power was low. At Williamstown recruitment was only 5% of the population, so it didn't cause excessive noise. This example shows that you can never say how many sites are needed to give high power (in a general sense). You need to be case sensitive. Differences in things like exposure, rock types, may make variances differ between areas, limiting the ability to simplify.

Other points to consider are that when you are making the leap from broad policy objectives to specific management objectives of a park, and then onto a more specific statistical design and a precise statistical model, you need to understand that the model gives a really precise answer to a really precise question. If you are not really clear about the question then you can't make sense of the answer. The link needs to be kept clearly in mind. If you specify a statistical model precisely then you can give clear recommendations on sampling design. We cannot do this if a model is not specified.

Although a lot of attention here has been paid to defining power levels properly, there are a couple of things to remember. Power calculations are rough things to do. They are based on preliminary estimates of variables in the system and on a judgement of what an important change is. Often preliminary estimates are really rough so we can only tell the difference in sampling effort needed between 6 and 26 not 5 and 6, so you can't get caught up in precise values. To define power we need to define clearly the types of change. Step change or gradual or quadratic types of trends?

We need to choose the effort in sampling to pick up that change. But we need to be flexible and explore a wide range of models. Chances are your data don't follow normal patterns and need special statistics to deal with non-normal data, and that's why you need a statistician on board. You need clear logic and a clear model. Variance structures are likely to vary between places so therefore you are not likely to get the best design for every situation but you can have a rigorous approach to designing the design. In the finish we need to decide what constitutes an important change, 50%, 20% in a population? This is the single most difficult step in the whole process, defining effect size. There needs to be significant biologist/manager interaction, especially as the two groups have different expectations but it is the single most critical step.

Workshop discussion

Craig Johnson: I concur in that the toughest thing is defining an effect size, it is often a subjective decision and the hardest point in power analysis. From practical experience I have found that when a pilot study is undertaken it indicated too many samples were needed but when the work was undertaken, significant results were found anyway, so the pilot data wasn't a great reflection of real variability.

Mick Keough: My cynical comment is that you have been lucky, and that is a risky strategy. Power calculations can be turned around to indicate the size of an effect that can be detected given a certain sample size (say the maximum practicable).

Malcolm Haddon: Power calculations are almost ad hoc. How big an impact you are hoping to detect is the problem. You never know the magnitude of change you will find so you continue the experiment anyway hoping to get that level of change so an effect is detected.

Mick Keough: At least by looking at the data you can get an idea if there is a risk due to high variability or not.

Nick Otway. There are advantages of manipulation studies in being able to ask specific questions on various degrees of imposition on a system. These manipulation studies can help determine likely effect size in observational studies.

Mick Keough: The question for parks is how much do things have to improve before an area is declared a success. But the question is sociopolitical really.

Malcolm Haddon: Decline in lobsters is a major impact and is an effect. Closure is a treatment.

Mick Keough: A lot of answers in species like this can be roughly estimated by fisheries modelling from catch rates. If catch rates are ‘x’ per year then when you remove effort, the change is ‘x’ per year, giving an idea of effect size.

Tim Lynch: A question regarding the spatial scale of controls. What is a reasonable spatial scale for establishing controls for a place like Jervis Bay/

Mick Keough: That sounds like a Sydney deep water outfall question to me!

Nick Otway: In a study I’ve been involved with in Hong Kong, a sewage outfall study had reference locations spread all around the Hong Kong waters, with a large variety of water types involved. Nineteen million dollars was spent but there was no result because the variability between controls was excessive, swamping the information.

Mick Keough: An MPA is not like sewage where you need to get away from a sewage plume etc., changes are due to things like the growth of juveniles, so it is good to keep controls as close as possible.

Tim Lynch: At Jervis Bay at what scale, within the bay?

Mick Keough: Controls should be as close as possible without being impacted by the effect of the reserve. So in a multiple zoned park like Jervis Bay then controls within the bay close to protected areas would be fine.

Malcolm Haddon: I have a question about fixed transects (ie bolted to the reef) e.g. Gary says fixed gives more power over random. What is your feeling?

Mick Keough: Maybe. It depends on the variance structure. If there is a lot of small scale spatial variation, but if those places stay different through time then a randomised strategy has a lot of apparent noise. Under these conditions a fixed transect allows change through time to be measured, giving a good clear signal. If there is a lot of temporal variation, then a random strategy is fine, it depends on the local system. A fixed transect design is difficult in that you always need to find the transect, year after year. A lost transect causes substantial statistical problems. Locations within control/impact areas are fixed entities anyway so it depends on the the sub-samples you want. If the place is different within a site then go with fixed transects, especially if the site is easy to find and transects are easy to find. But if there are mobile organisms or big recruitment pulses then random may be fine, finding the transects is often the biggest problem.

Malclom Haddon: If you can stratify adequately, then by all means randomise within strata, if you can’t then go with fixed transects, but often finding fixed transects is difficult, even on a good day.

Alan Jordan: When you have recruitment variability influencing the spatial scales of sampling, how important is it to quantify spatial scale variation?

Mick Keough: Using hierachial methods you can measure the scale at a site then adopt sampling strategies to average that out. Otherwise you have to try to stratify, try to identify high and low recruitment locations or sample enough to get rid of small sample noise.

Alan Jordan: Is it possible to use different models to analyse different species e.g. abalone and scalefish?

Mick Keough: You can use the same models but use different sampling strategies to get rid of small scale noise, for example this was the case in the Tasmanian study with three different methods for fish, invertebrates and algae.

Malcolm Haddon: With the bastard trumpeter data Graham has shown, most of the result is due to recruitment of one year class moving through. This is really auto-correlation, with the next year being predictable from the last. You can better model this data than use classical statistics.

Graham Edgar: This is a particularly bad example statistics wise!

Mick Keough: It is a particularly good one really, in that you don’t need statistics to see the effect.

Caleb Gardner: The problem with the trumpeter data is in not having an obvious recruitment pulse in areas outside the reserve. We need a better idea of recruitment pattern more broadly for identifying fisheries benefits.

Mick Keough: It is a problem in not being able to measure recruitment in all species at all times, and the luxury of before years in reserve areas. There are so few species where we have a good picture of recruitment variability.

Mick Keough: Getting back to Malcolm’s point regarding modelling, there is a whole family of spatial statistics that allows us to model out small scale spatial variation in recruitment. There are whole books on the subject, but the field is new to biologists. You need to think carefully about how you sample spatially, but they are potentially really useful techniques. They enhance the power of the main test by reducing noise.

Nick Otway: Many people here are managing existing parks with no prior monitoring so it is a case of ACI rather than BACI, what are your comments?

Mick Keough: Without before or time series data you are quite weak in your ability to draw conclusions. In the Williamstown data there was no difference between protected and unprotected harvested species when this was examined after 75 years of protection. But after the area was opened up, there was a significant decline in the size of some species, so inferences based just on the differences between closed and open areas would have been wrong. In areas recently closed there is still the opportunity to observe divergence. By collecting time series data, linear or quadratic trends can be tested for. But after 10-20 years it may be too late to look at trends. In a park like GBRMPA where areas are continually being opened and closed however, these things are easy to do!

4.2 Practical statistical design requirements - Open discussion on the types and magnitude of change we want to detect - Chaired by Malcolm Haddon.

Malcolm: We would like to hear from the gathered managers, biologists and statisticians, what scales of changes have been detected within parks, and what is feasible to detect, and what is desired. So to start off, what sort of levels do managers want to detect?

Karen Edyvane: You would be looking at 20% as a level where you would start to think about remedial measures, as by the time a process gets going for remediation, this may have reached 40%.

Malcolm Haddon: But many organisms vary by that much as part of a dynamic equilibrium.

Karen Edyvane: That is a population focus but you need to look at communities, 20% habitat change may be more real than 20% change in a dynamic species. In future, MPAs will be multiple use so we will be measuring all sorts of change, for example fishing methods.

Laurie Ferns: There is some consensus on looking at change in community composition, perhaps by a multivariate approach.

Malcolm Haddon: At the Plymouth Marine Labs, North Sea studies have shown community change but the difficulty is in finding what they relate to. There are some new non-parametric models for hypothesis testing. Is anyone using them here?

Laurie Ferns: There is a potential problem with introduced algae causing community shifts. It would be nice to look at overall community effects.

Malcolm Haddon: There is a problem in defining variability within individual populations, when you expand that to communities you increase the problem. Not enough is yet known about community variability to guess at what is acceptable change.

Hugh Sweatman: There is some data from the GBR on assemblages of fishes so we can use this sort of long-term database to approach the problem.

Malclom Haddon: There are methods available for comparing similarity matrices but as yet I have not seen ways of coping with a time variable.

Gary Davis: One measure of what is useful is a measure of standard , if a species changes by say one standard deviation per year for three years, or by three standard deviations in one year, then there may be a problem.

Malcolm Haddon: This could be a good approach as it gets away from guessing a particular value but detects substantial change.

Matthew Edmunds: In a long-term before/after outfall pipe monitoring study I was involved with, we used community based matrices to look at change over time. Before the change the community data near the outfall plotted as a cloud at a particular point in hyperspace, and the position of this cloud shifted notably after the change. So if there is a way of measuring this trend it would be a logical and useful way of measuring change. The univariate data associated with this study showed no significant change, so the multivariate data was more powerful.

Malcolm Haddon: Where there biologically interesting differences?

Matthew: Definitely, but at the species level none was detected with the power used.

Nick Otway: In a seagrass study we found a 30% change in *Zostera* was detected with a big sampling effort, but this could be 40-50% as variability increases.

Malcolm Haddon: This % change can be time of year related as well as where it fits on a change curve.

Alan Butler: The multivariate approach is a good one but isn’t necessarily the way to go because the real point is you need to know the questions you want answered and then go and get the techniques that are most appropriate for answering them.

Malcolm Haddon: The multivariate approach has a big question mark really as the techniques are under-developed.

Hugh Sweatman: Fish populations are variable from year to year, maybe we need to sort out the data to ask which species are declining more than usual and ignore the rest as a starting point. Use univariate methods to determine to magnitude of change.

Graham Edgar: The changes of interest are often trends going up as well as those in decline.

Malcolm Haddon: The GBR model is so big that it is looking at a whole system rather than sites so we need to determine the scales of interest. Are we worried about sites or larger scales?

Mick Keough: If the practical aim of an MPA is to protect heavily exploited species then 20% is not much gain for them. Maybe 50-100% gain is the level you would want to detect (abundance), and about a 20% size increase, as that often relates to a substantial biomass increase. Another point is that loss is not always an issue as loss can often be part of ecosystem shifts.

Graham Edgar: A comment from empirical data regarding power. At Maria Island we had six sites fished and six sites protected. With log transformed data this allowed us to detect 100% increases and 50% decreases in the most common species. With untransformed species richness data, 15% change could be detected, and these are biological significant changes.

Malcolm Haddon: There is an issue with measuring mean size in that in a fisheries sense you can measure large numbers of animals and get a significant difference for only a small change. Is it meaningful though?

Graham Edgar: This depends on the species and sizes. For lobsters 10% change can be very important in a fishery fished down to the legal size, especially as that 10% may relate to a 50% increase in biomass and egg production.

Nancy Dahl-Tacconi: Numbers vary so much you need specific questions for specific objectives. If the objective of a park is to minimise fishing impacts then 50-200% change in fished species may be a useful detection limit but if the objective is to eliminate an impact on an endangered species then 1% may be too much.

Gary Davis: You need to be careful about what to specify. For example lobsters in California can be very long-lived. It can take 25 years before size changes have a biological result as mating with females does not take place until this size/age is reached in males. So the issue can be time sensitive and tied to specific life history and ecology.

John Gilliland: Individuals of an invasive species can be critical too, you might want to detect them at very low levels.

Mick Keough: Some models have been developed for detection of rare species. In monitoring invasive species we need to understand their ability to become established in disturbed areas compared with undisturbed. But we need lots of areas to test this.

Malcolm Haddon/Gary Davis: That is a big question and there are plenty of examples from the terrestrial side that pest species flourish in disturbed areas. Is it the same for marine?

Karen Edyvane: Biodiversity is the direction of the current NRSMPA program that the states are involved with. So what is core and non-core biodiversity and a good means of monitoring it?

Matthew Edmunds: Studies at Homebush Bay indicates species richness is not just a key factor. It went up due to the introduction of new species. The Environment Australia specified indicators are guidelines, but very general and not specifically related to specific impacts.

Karen Edyvane: Things like habitats are important to measure.

Graham Edgar: Species like *Centrostephanus* can upset the habitats within and outside MPAs. You need to know the system at each MPA and that external to it, before determining a response to change.

Nick Otway: Temporal and spatial scales of variation is a question. Management plans in NSW are renewed every 5 years so we need to detect change within that time-frame to develop a response.

Malcolm Haddon. If there is a big change we simply need to be aware of it.

Gary Davis: Systems change with long-term environmental cycles like El Nino. Giant kelp varies greatly between years, however recovery is slower in fished and disturbed areas. We want to know what the influence of this disturbance is.

Malcolm Haddon: In modelling terms you are talking about return times and stability. A possible way of examining that is to take a multivariate approach examining community migrations like the North Sea study.

Janet Slater: There is a general consensus that water quality is important to measure.

Leanne: There is difficulty in the precision of water quality measurements in bays and estuaries, and these measurements are very costly. It may be better to look at intergrated biological responses, tissue body burdens etc (like Gary's DDT example in California).

Nick Otway: When testing against standards you have a one-tailed test, increasing power.

Laurie Ferns: With major habitat types like seagrass, kelp forests, reef, there may be different triggers for change on each, but we know fishing and sediment loading can be important in causing change and we want to get a good idea of what factors are important.

Malcolm Haddon: For seagrass you can use aerial photos for measuring change.

Leanne. In Victoria a lot of spatial and temporal change has been recorded in seagrass beds. A 20% trigger may be inappropriate as we expect this kind of change. We need to know if the change is natural or anthropogenic.

Neville Barrett: Studies on reefs have documented fishing as possibly the most important factor causing chance, and therefore a major role of MPAs is in acting as reference areas for fisheries managers. For this role we should be able to decide what magnitudes of change in fished species we want to detect. This would be in the order of 50% increases in abundance, and 20% in size. The magnitude of this change will be related to the extent of external fishing as much as anything, and will give a reasonable indication of the levels of that fishing. It is valuable historical data in the absence of long term records on species abundances and very useful in enabling better management of fish stocks outside the MPA. In this case the trigger is related to management of stocks outside the MPA, not management of the MPA itself, except to determine if the MPA is successful in protecting the species within it.

Karen Edyvane: Biodiversity is where it is at as far as the NSRMPA is concerned. Gary's model examining taxa is the way to go, looking at all interractions. Current fisheries prescriptions are not in concrete so they can be changed in response to information from MPAs.

Neville Barrett: One clear point is that by examining changes to fished species you are not just looking at fisheries related questions, you can look at secondary changes such as habitat shifts and be able to relate cause to effect. Just concentrating on communities or habitats will detect an effect but not a cause.

Karen Edyvane: We want to look at things like seabird/mammal foraging to determine buffer zones and appropriate areas to protect.

Malcolm Haddon: This doesn't give effect information, only size information.

Neville Barrett: The point of today's exercise is to discuss effects that can be detected by the techniques we are using (UVC) in coastal MPAs.

Matthew Edmunds: The idea would be to gain as much information as possible within logistic constraints.

Malcolm Haddon: Gary, would you say a lot of what you detected in the way of change was planned or fortuitous?

Matthew Edmunds: Gary's process was an iterative one, which was good but that should not delay any initial start to work here. It helps to start with what is known to be informative and useful and build on that.

Nick Otway: A major research plan is needed and funding to guarantee outcomes. In NSW unless there is a major plan specifying performance outcomes it will not get the tick to start monitoring.

Malcolm Haddon: There are usually very few funds available, unlike the case in Gary's study. This afternoons session probably did not result in any questions being answered but I didn't really think they would be. The answer really depends on the questions being asked, whether that is about organisms, communities, habitats, ranges, and what the outcomes are that are needed.

End day 1.

5. Session 3. Underwater visual count techniques – Chaired by Graham Edgar.

The aim of this session was to discuss the advantages and limitations of underwater visual count techniques, particularly those currently in use, and try to find a consensus on the best techniques for monitoring coastal MPAs. To focus this session, and to facilitate discussion, there were three informal talks. The first was by Neville Barrett, discussing the range of UVC techniques currently used in fish census. The second talk was by Matthew Edmunds discussing census of lobster populations, and the final talk was by Rick Officer, discussing abalone census methods.

Graham Edgar: To start off with it would be good to backtrack for five minutes to see if we can get some biological agreement. The question is if we are collecting baseline information, what is the minimum amount of power and replication required. Gary commented that for biodiversity how and what you measure is important, but for the population dynamics of species, particularly those of interest to fisheries managers, it might be possible to decide on fixed figures. Examples might an IUCN type value where a species is potentially threatened if there is a 50% decline in abundance over ten years. Can we come up with something like Gary’s three standard deviations over three years. A trend or sudden jump detected by automatic screening. Can any of the management questions be quantified?

Malcolm Haddon: There is a question of scale. Region or site levels, species or communities, ecosystem or habitats, time series and power. Larger times give you more chance of detecting change.

Graham Edgar: We might leave things there.

5.1 UVC techniques currently in use in temperate Australia – Neville Barrett

This is intended to be an informal talk, hopefully facilitating discussion about the merits of each technique with people sharing ideas and experiences so feel free to contribute. UVC techniques are particularly flexible and adaptable. They can be random, giving relative values, and highly stratified to give absolute values. They provide information that is independent of fishery data, and can provide rapid assessment of size structures. The techniques are non-destructive, and can be modified to be broadly applicable to a wide range of species, including fishes, invertebrates (including corals), and macroalgae. The non-destructive component is particularly important when working in the small MPAs of temperate Australia where any destructive techniques could have substantial impacts on the species in question.

There are a number of limits to UVC though. One of these is the depth/time interaction due to nitrogen build-up. Most of the Tasmanian MPA study involves sites in shallow water (5 m) where divers can work all day, however in some areas the shallow depths are not representative of the communities present, and there is a need to work deeper.

At the Governor Island reserve at Bicheno, reefs extend into 40 m and it is at depths below 10 m where the most stable communities exist. As this coast is subject to reasonably high wave exposure, the community present at depths less than 10 m is relatively simple, reflecting the sub-set of species that are tolerant to high energy zones. Other problems with UVC include the cold waters of temperate zones that limit dive times and cause diver fatigue, and the effects of diver bias and training.

Avoidance and attraction to divers by some species can limit the quantitative ability of these methods. At Leigh in New Zealand snapper are strongly attracted to divers now the area is fully protected and fish are actively fed by divers. Any time series data following the recovery of this reserve therefore needs to be interpreted in the light of increased counts due to increasing diver attraction. Variability in abundance is also a difficulty. In any ANOVA design, sample sizes need to be large enough to avoid obtaining too many zero counts, and this can be a problem for many of the less common species in an assemblage. As Mick Keough and others have pointed out, a pilot study is needed to initially examine what is possible and perhaps pick out the less variable species and use them as indicators.

Visibility can be an important issue as it can vary substantially between sites and times and can influence counts by limiting a divers ability to detect species when they are there, and in poor visibility many mobile species actively avoid divers, reducing counts.

Differing types of habitats can influence how visible species are as well. For example in NSW urchin barren areas contain little algal cover and fish are highly visible, but in thick *Ecklonia* forests, fish below the canopy may go undetected. This is not a problem in stable habitats as you are often comparing relative abundances through time, but when there is a change from barrens to kelp forest there will be a bias due to reduced ability to detect fishes.

Nick Otway: Is the time of day important?

Neville Barrett: Often for fishes yes, but we limit the time of sampling to the middle of the day where behaviour is less variable. In winter this might be between 10am and 3pm when light levels are high. Sites are randomly sampled at each survey period to ensure there is no systematic bias due to time of day or other factors such as cloud cover, or changes in visibility.

One widely used transect method is the **strip transect** where a diver reels out a transect line, or it is set from a boat, and the diver searches a fixed width along the line, and usually on both sides of the line. One commonly used method is to swim in the middle of a 5 m wide lane on one side of the line (estimating the width of the lane) for a distance of 50 m, then returning on the other side of the line, searching a 50 m by 10 m block. This is the method used for counting the abundance of fishes and estimating their sizes in the Tasmanian study. At each site there are four replicate transects placed end to end, usually around the 5 m depth contour.

A modification of this method is the **belt transect** where two lines are laid out, and the diver swims the lane in-between. The advantage of this is that the area searched is more quantitative.

Matthew Edmunds: Have any comparisons been done between counts on up and down lane counts?

Graham Edgar: No, but as the transect is laid there is a similar disturbance so they would be similar.

Gary Davis: We have examined this in our studies and found no differences.

Neville: We have not recorded up and down lanes, they are pooled for each 50m block. The thing to remember is that the same method is used each time and at each site so everything is comparable.

Colin Buxton: You could lay transects from a boat to minimise differences.

Neville Barrett: The problem we encounter with that is we are trying to lay around depth contours to minimise depth related effects, and that is often difficult to do from a boat.

Malcolm Haddon: Fixed transects could be better.

Neville Barrett: I'm in agreement but we have never had the time or resources to do that.

Nick Otway: Have you tried fixing the tape and swimming with it?

Neville Barrett: There is an element of difficulty in using this method (reeling out tapes while recording data), but it is a commonly used method.

Graham Edgar: You only get half as much data as you can only search a 5m wide strip.

Neville Barrett: There are also problems in width estimates as you do not have a line on one side to estimate distance from.

Graham Edgar: Gary, what were the costs of establishing fixed transects?

Gary Davis: The costs were relative because the fixed transects solved more problems than they caused. It took approximately half a day to establish each transect. We used a hydraulic jack-hammer to drill holes in which stainless steel eyelets were placed. Lead core lines were run between eyelets that were spaced 10 m apart. The lines were fixed to each eyelet so if one section of line was broken it did not disturb the rest. When surveying a site, the transect tape is layed out alongside the marker line. There is no real problem with disturbance.

Nick Otway: Pneumatic drills are ok for drilling holes too.

Gary Davis: Pneumatic is more powerful, but it did require specialised surface equipment to power the drills. It cost $50000 US in 1980 to drill the holes and establish the lines. This included 7 weeks of vessel time for all sites, 8 divers. In year one the sites were picked, in year two they were established, and in year three the surveys started.

NevilleBarrett: **Line methods** are a transect variant, used and discussed by Gunn and Thresher. This involves estimating fish angles and distances, and using probability functions to gain corrected density estimates.

Timed swims are another commonly used method. These are usually in the order of ten minutes, where a diver estimates a lane width, and swims at a constant speed.

The final method in common use is the **stationary visual technique**, where a diver counts the species of interest within a fixed radius of the diver in a short period of time. It is particularly useful where fish behaviour can interfere with counts, especially strong attraction.

All of these techniques have a number of advantages and disadvantages.

Strip and belt transects give good relative abundance estimates, and can also give size information. You can combine multiple species counts in certain areas (not in high diversity areas like the GBR , but it works well in Tasmania). It is rare to get overwhelmed in temperate Australia. Large amounts of information on many species can be gathered, within a known area giving some estimates of abundance. Disadvantages include the effect of changing visibility, diver bias, time laying transects, and fish avoidance and attraction.

Colin Buxton: Is there a cut-off point where visibility is too poor?

NevilleBarrett: Yes, we stop when visibility drops below 7 m.

Colin Buxton: Have you quantified the effect of visibility on counts.

Neville Barrett: Not as yet, but we have the data and will be examining it as part of our FRDC research.

Neville Barrett: Line transects are a method that gives good density estimates but is time consuming. Angles need to be measured to target fish, and distances estimated. The chance of observer errors are high.

Leanne: The method has been used in seagrass reasonably well. The flat contours simplify the technique.

NevilleBarrett: There is certainly more difficulty in areas of high 3d structure.

Malcolm Haddon: What do you do in areas with massive structure? This must also influence the searched area?

Neville Barrett: The depth contours are followed where possible, minimising the ups and downs, and while different areas may be searched between sites of different rugosity, their relative differences remain constant when the sites are repeatedly surveyed.

Neville Barrett: Rapid visual counts (timed swims) are good for rapid assessment of areas. They give good qualitative data but not quantitative. Estimates can be quite variable between divers, with no references to estimate strip widths or distances swum. Good visibility is also needed. However with new underwater diver positioning systems (dive-tracker), it may be easy to map out the areas and distances swum. This technology may greatly enhance the advantages of this technique in the future.

Stationary visual counts have a number of advantages including counting species that are difficult to count on transects due to diver interactions. Search areas can be reasonably estimated in an arc around the diver, and as a small area is searched at each count the method is useful for stratifying counts between differing habitats. Size information can be gathered as well as abundance, and the method is adaptable to the use of baits, although when this is done the results are not at all quantitative, and are more of use for presence absence data.

Video transects. Video is a tool that can be adapted to most of the techniques previously discussed. There are a number of significant advantages, including the ability to replay the tape, it also offers a permanent record and the ability to use divers with little biological training. It can be adapted to situations where a diver is not required (perhaps time lapse monitoring of bait stations) or is unable to be present, such as when depth and time become limiting factors. ROV's can be used for deep water transects, overcoming depth constraints.

Disadvantages of video include the overall cost, estimation of size, available search area, and problems with light and color. The cost of a single video and housing is not substantial (approximately $7000 for a unit with lights), and this level of technology is ideal for the type of coral cover transects that Hugh has used. However, for quantitative transects, especially where size and distance estimates are required, costs escalate as stereo video is needed, or a unit that interfaces with a distance estimating laser. In open areas such as coral reefs, or temperate reefs beyond algal depths, this technology might still be cost effective, however in areas where a thick algal cover is present it is unlikely to succeed.

One of the greatest limitations is the inability of videos to perform under high contrast situations, where in high light situations, darker areas cannot be seen. Color is also a problem where it is needed for the identification of species, as color is rapidly lost with depth, although the latest 3 chip digital cameras are a substantial improvement in this area. One final problem with using this technology is that after the video is taken, there is time consuming analysis involved back in the lab, so any saving made using an untrained diver may be lost by needing a trained observer to interpret the video.

Colin Buxton: Recent developments with duel lasers has substantially improved the ability to estimate search areas and fish sizes with video.

Janet Slater: Video is good for invertebrate work at depth, especially as you can do real-time work if you have a monitor on the boat. With GPS technology you can get reasonably quantitative estimates of the area surveyed.

Malcolm Haddon: Also with invertebrates, there are some advantages when surveying fixed quadrats.

Sam Ibbott: Video is best under 2D situations, in highly structured reefs with caves, a lot of information is missed by video.

Nick Otway: Depending on the sampling strategy, you could stratify by type, e.g. reef top, caves, crevices.

Hugh Sweatman: A fundamental problem with video is that underwater visibility is much poorer than with the human eye so a lot of information is lost.

Gary Davis: There have been lots of comparisons in the US with visual compared with video. Often fish were observed by divers but not seen on the video. It appears to be a 3D movement effect. Another problem is that you cannot keep track of fishes that circle divers. With video the fish may be recounted several times. In our studies we use visual transects because we found them to be much better than video at our sites, but we do use video to keep records. They are a great interpretation and education tool.

Neville Barrett: Returning to strip transects, they are by far the most commonly used method for quantitative estimates of fish abundance in Australasia and the US. The unit size varies between studies, but 50 m x 10 m is commonly chosen. For many reef species of interest this size usually yields reasonable counts.

Malcolm Haddon: Is this size chosen because it is easily done or that it gives the best results?

Neville Barrett/Matthew Edmunds: A mixture really, some studies have examined optimal size and power, others have not, but there is general agreement that this size gives reasonably robust data in many cases.

Rick Officer: You have not mentioned adaptive sampling techniques. For example aggregating species.

NevilleBarrett: For some species there is not enough information per transect, particularly for getting a good size estimate, in cases like that you really need to focus on the species of interest and adapt your techniques accordingly. If transects are not working alternative techniques may be necessary. For example to get good mean size estimates for abalone in sparse areas, you may need to search specifically for individuals to measure.

Nick Otway: That is not really adaptive, just a different question.

Rick Officer: This was really an abundance related question.

Malcolm Haddon: You need to stratify to do this, and there are lots of methods.

Neville Barrett: The technique we currently use maximises the information gained across a range of species, but it also highlights problems where numbers are too low or variable. For example at Maria Island, the mean value across six sites for the abundance of the blue-throated wrasse has a low error compared with the mean and we are able to detect meaningful levels of change in the abundance and size of this species. However, with the toothbrush leatherjacket, the variability was much higher and a lot more replication would be needed before changes were detected.

Mick Keough examined the results of surveys at the Wilsons Promontory and Bunerong Marine Parks from the early 90s and found that for many reef species, a very high degree of replication would be required to detect biologically meaningful changes. However, there was a small subset of species that had lower variability and that would be suitable indicator species for monitoring. So these techniques do work for a range of species, (but not all, without excessive replication or transect size), and while changes cannot be detected in all species, collecting the information is still highly useful for examining species richness and the value of this should not be discounted.

5.2 UVC techniques for examining rock lobster populations - Matthew Edmunds.

For rock lobsters there have really only been four programs that have examined long-term changes in populations. These have used widely differing methods. One study at Stewart Island in New Zealand used timed swims and measured about 10 lobsters per hour. This had the problem of being difficult to compare between areas, and was very intensive. Another study, at Leigh in New Zealand, used area counts to examine reserve effectiveness. 10 m x 10 m quadrats were used giving density estimated between 8-10 per 100 square metres. In that study, the clumped distribution of lobsters was a problem. Large sample sizes and stratification by habitat was required to get estimates reasonable, and even then variance was high.

In the Tasmanian study examining the early benthic phase, a 24 m x 32 m quadrat was searched intensively. Each month this 700 m^2 area was searched giving estimates of total abundance ranging from 3-8 lobsters per 100 m^2. The variability was due to middle sizes juveniles being highly aggregated, but with those aggregations moving. So there was a clumping problem influencing the means data. When co-habitation was examined, in some months lobsters were sharing shelters, and in other months they were not, so there were varying variance structures. Size frequencies were much more stable through time. The question is how do you estimate the abundance of a clumping animal? Strip transects may not be the best method.

Tim Lynch: Are clumping patterns seasonal?

Matthew Edmunds: There is some degree of predictability but there seems to be a lot of noise too. To get decent means you would probably need to search 1500 to 3000 m^2.

Malcolm Haddon: The central limit theorem states if you take enough samples you will eventually get there!

Matthew Edmunds: The size structure of holes can influence population dynamics, so rock type can be important, particularly in site comparisons.

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5.3 UVC techniques for examining abalone populations - Rick Officer

Rick Officer: Matthew's talk was a good introduction to mine as rock lobsters have often been called abalone with legs. Both species have similar problems when it comes to assessing abundance because of their distributions. With abalone it is a case of clumping and non-clumping and the hyper-stability of clumps. The problem for determining changes in abalone abundance comes when there is a commercial diver about. Divers preferentially fish aggregations until the aggregations are gone. The abalone respond by preferential movement back into these high quality habitats, so there is a change in abundance in the lower quality habitats, but not the top quality ones.

Now for fixed transects focused on estimating abalone numbers, counts are normally in areas of reasonable abundance (as you try to avoid counts of zero), and because of the hyperstability of the clumps in these areas you miss the changes. There is also the question of cryptic animals replacing the emergent ones.

Malcolm Haddon: This is certainly a black hole with abalone, the presence of animals under rocks, emerging to replace those lost to fishing. As the abalone researchers have a problem with just one species, perhaps surveys should focus on just a few species, using the techniques you know will work. Good data is much better than marginal data.

Graham Edgar: A question about abalone estimates then, what techniques would you say were useful for an area like Wilsons Promontory, where abalone are relatively abundant?

Rick Officer: Distance based estimates using a bootstrap approach with the nearest neighbour estimates of distance. You need to map all individuals and stratify carefully. Otherwise you need to remove all clumps from the dataset, you are then left with the sparsely distributed individuals that may be more indicative of real changes in abundances.

Tim Lynch: What proportion of the population are usually in clumps?

Rick Officer: Most are in clumps. So if you want to avoid them you need to avoid methodologies that attract you to aggregations.

Gary Davis: What is the spatial separation between clumps. 50 m, 100 m?

Rick Officer: In complex bottom it can be more like 5 m. In New Zealand and South Australia they are using clump frequency and size, instead of individuals, for monitoring populations. As density goes up, the best quality real estate is filled first, and then the less popular areas get filled, and this can lead to variance problems with the data.

Matthew Edmunds: The transect method can incorporate clump information by noting the position of clumps along the transect. That would also give spatial information on clumps.

Rick Officer: If one of the aims is to sell this information to fishermen then clump information is useful because that is what they fish. So it can help to target things they are interested in to help get the information across.

Malcolm Haddon: Are abalone good to measure anyway? For example poachers might come in and take them from reserves. Is it possible no increase in abundance was noted at Maria Island because poachers prevented that increase.

Graham Edgar/Rick Officer/Neville Barrett: There is some poaching there but at low levels. The rangers on the island closely monitor activity there.

Malcolm Haddon: Is it still a good species to look at? Stealing could lead to mis-information.

Rick Officer: Yes, because it is a major fisheries species and people want to know the differences between fished and protected areas.

Matthew Edmunds: Size frequency structures will pick up poaching if it is at significant levels.

Graham Edgar: You really need lots of data for that though, as the effects of poaching are very localised.

End of session.

6. Sessions 4 & 5. Towards developing a consensus on appropriate standard methodology, and possible alternative methods.

6.1 Open Discussion - Chair: Gary Davis.

Due to the flexibility of the program, more time was allowed for the previous sessions and so the final two sessions were merged into one. The aim of these sessions was to try to develop a consensus on an appropriate standard UVC methodology so that the results of researchers working in differing states could be compared. This would facilitate answers to questions such as what are effective MPA sizes and shapes. Additionally, by developing standard techniques, we may enhance the quality of research in this area. Where UVC techniques do not work effectively, we need to explore alternative methods that may yield reliable abundance and size distribution estimates.

Gary Davis: We need to nail down some questions we want answered. The main questions are about the efficacy of MPAs to protect biodiversity and systems, and perhaps the role as a refuge from fishing. Questions revolve around the size and shape, how do we address this and distribution and numbers around the coast? We need to test these questions. So will the use of the strip transect methods allow us to answer a lot of those questions? If not, we want suggestions about what will allow us to address them. Maybe information like fishing fleet effort around boundaries. So in the next 90 minutes we want to sort out our ability to do this and come up with alternatives if not.

Rick Officer: Need to step back one step first and ask what each MPA is intended to achieve in the first place. Is it biodiversity, social factors, fisheries management? If it is fisheries managment then I believe lots of little ones would be best.

Colin Buxton: We could talk about this aspect for days, but the focus of the NRSMPA is on biodiversity so we need to focus on the success of the NRSMPA.

Laurie Ferns: The major thrust of the NRSMPA is about stopping threats to biodiversity

Malcolm Haddon: So questions about abalone are better focussed around stopping threats than about fisheries benefits.

Colin Buxton: Can we assume the bioregions are appropriate? Assume we want to select a zone within this region. How do we go about selecting this area and about seeing if it is working?

Malcolm Haddon: The question is really whether we can detect the maintenance of the status quo or changes.

Colin Buxton: We need to discuss how to monitor and count what is in closed areas, not the next level of contribution to biodiversity.

Leanne Gunthorpe. Not all areas are rocky reef, the habitat examined so far, what about seagrass, soft sediments, sponge gardens, the intertidal zone, etc.?

Tim Lynch: In NSW the focus is on protecting all areas so we need to assess them all.

Leanne Gunthorpe: Most of the other habitats can also be examined by UVC methods.

Malcolm Haddon: We need to recognise that people here are focussed on a whole range of different issues, whole systems, deep water, differing habitats. We need to take a subset and examine them within the aims of the workshop.

Laurie Ferns: There have been plenty of seagrass workshops looking at this issue.

Matthew Edmunds: I think we should stay with the reef focus, there are more site attached species and they are easier to monitor.

Laurie Ferns: The sampling unit methodology should be a focus, how are you going to send someone into the water and be confident the information collected is useful? If someone says they can pot lobsters or fishes and get the same result for less cost, we want to know if it is better, or more cost effective.

Malcolm Haddon: We should start with no-impact techniques, so potting might be OK if everything goes back alive but if fish in the deeper waters are killed by swim bladder inflation then it will not be acceptable.

Sam Ibbott: If we are examining biodiversity the question is what to count?

General comment: Indicator species are better than trying to count everything.

Colin Buxton: From the indicator perspective, drivers of systems might be better to follow, along the lines of the keystone concept.

Nick Otway: You should pick up a set of trophic levels and then select species within them, with a range of feeding types.

Gary Davis: If we are really about protecting biodiversity we need to understand that you cannot examine every species. You do need surrogates and to define a selection criteria for identifying them. So what are the criteria - Trophic levels, feeding strategies, lifespan (short and long)?

Malcolm Haddon: Weedy invasive species are good indicators of disturbance.

Nick Otway: If we want to detect change, we need responsive species, so it could be best to concentrate on variable species.

Malcolm Haddon: Long-lived more stable species might be best though, as a shift in these species has meaning, and will not be swamped by variation. So most of these resilient species will be long-lived and large.

Gary Davis: Even short-lived species can be stable though.

David Harasti: The time frame of a monitoring program can be an issue. Can you pick species that will respond within the length of a funding program?

Nancy Dahl-Tacconi: Politically powerful species, the charismatic species might be very useful, including rare species.

Colin Buxton: On the issue of macroscopic/microscopic, it would be best if we focus on the macroscopic due to cost, training etc, but in some cases such as salmonid farms the microscopic infauna may be the way to go.

Tim Lynch: The focus should be on species with a good taxonomic understanding.

Gary Davis: If a chosen technique was applied to different states, would there be a big difference in the taxa selected for monitoring? (as a group rather than individual species).

General comment: The key taxa are shared widely around temperate Australia.

Rick Officer: It is helpful to choose species that something is known about if you have to make a choice.

David Harasti: You could possibly ignore abalone then, if it is known to be too difficult.

General comment: Abalone cannot be ignored as they are often a major component of reef invertebrate communities. They could even be dealt with as clumps as Rick suggested.

Neville Barrett: Abalone are a component of diversity and cannot be ignored, other invertebrates have similar characteristics and if you ignore them too, you will lose your biodiversity information.

Gary Davis: With regard to political constituencies, does abalone fit in?

Laurie Ferns: Selecting abalone is certainly important from a political and cultural point of view.

Malcolm Haddon: If the system is biodiversity based, do we examine this by only looking at a few species?

Matthew Edmunds: In the Tasmanian work and the work in Victoria we look at hundreds of species.

Rick Officer: You can have an iterative process to look at what to follow and what to drop.

Graham Edgar: It is important to look at all sorts of things as reserves are complex and patchy, and all species vary between areas, even over small scales, so it is important to look widely.

Malcolm Haddon: One thing we should be looking at are areas that are impacted prior to protection.

Graham Edgar: The assumption is that these areas will be effective but we have no real understanding of what sizes will be effective. We might not be able to change areas if we find they have been made too small so we certainly need monitoring that looks at the influence of size.

Laurie Ferns: Generally change is due to people stopping taking things so we should focus on the things that they take.

Gary Davis: Is it reasonable to use surrogates for biodiversity to meet a legislative approach, or do we need to survey everything? All taxa surveys take forever, what time scales are we talking here, every year or three years?

Laurie Ferns: You don’t need to examine everything. There should be three scales of monitoring. At the megascale there is overall habitat change, examined by things like aerial photographs, at the mascroscale there is the visual census type of information, with data that is feasible to collect by a diver. At the microscale there are selective detailed studies at the species level, maybe concentrating on lobsters and abalone and others of particular interest to a management plan.

Gary Davis: In the US, there are similar levels. At the landscape scale, changes are examined every five years. Community structure is examined every 2-3 years, and demographics every one year. The demographics examine things like reproductive effort and recruitment.

Leanne Gunthorpe: Biodiversity may be a focus but realistically we need to incorporate other things into monitoring such as fisheries related questions. These are the questions people want answered politically.

Caleb Gardner: Abundance and mean size data just relate to effort reduction. But we need to know about the secondary effects of fishing reduction, are there special things we need greater measures of, including questions increased recruitment?

Laurie Ferns: Fisheries questions are fine but should form the focus of additional research. Managers want to know if the reserves are OK, and need monitoring that will pick up changes, even if they are patchy, perhaps as a result of point source pollution.

Nick Otway: In NSW ecological processes and biodiversity are what we are looking at. So we can use a mix of variables, including measuring sources and sinks. Do MPAs act as recruitment sources? We can look at reproduction rates as an indication of sources. This is intrusive but you do need information on reproduction. Visual surveys may detect recruitment into the area but reproductive information is needed and it is intrusive.

Malcolm Haddon: You might need to know more about the system before determining benefits. For example the increased larval output from lobsters in Tasmanian reserves might all end up in New Zealand.

Nick Otway: That is OK though, because we are not just looking at recruitment to the MPAs but whether they are good for the rest of Australia, and whether biodiversity is being enhanced more broadly.

Leanne Gunthorpe: With biodiversity you might also want to look outside of MPAs to see if the benefits spread further, to facilitate community acceptance and to see if there are flow-on effects.

Malcolm Haddon: That would be starting to become a very expensive exercise.

Gary Davis: The next step then is the selection of the distribution of sampling schemes, following on from the selection of taxa and species, and deciding what to measure (size, abundance, clumps, sex ratios). The question is where and if gradients are important.

Colin Buxton: A coral reef question - What is the significance of measuring shapes of corals, and is there a temperate reef equivalent?

Graham Edgar: Certainly the classification of macroalgae can be based on form.

Hugh Sweatmann: Part of the classification system for corals was based on observers not being able to handle the species, so the monitoring was taken one level above to simplify the process. There are some ecological correlations with shape.

Nick Otway: Sex ratios are very difficult to do.

Matthew Edmunds: For some species, they are easy and should be examined. For example, lobsters are easy and the sex ratios can have large ecological significance. Especially sex related size differences. There was a chastity belt experiment in lobsters that showed that if females don't get mated they can lose their reproductive ability and even die.

Gary Davis: Growth and mortality can be important issues.

Malcolm Haddon: Things like the *Centrostephanus* invasion will be detected far more easily by doing community studies than by habitat mapping.

Laurie ferns: But it is important to get habitat mapping underway.

Nancy Dahl-Tacconi: Managers making decisions about threats need to know if threats are being reduced, and they need to understand the process.

Matthew Edmunds/Nick Otway: Mapping at fine scales in places like NSW where you have barrens and algal canopy, will give good information on habitat change.

Laurie Ferns: You still need the other information to tell you why you get these changes, so species level information is important.

Nick Otway: It is important to be able to detect and interpret natural changes out of the ordinary. So you need areas for comparison.

Malcolm Haddon: And time series for comparison.

Matthew Edmunds: The method used by Graham and Neville in Tasmania uses quadrats along transect lines for algae, and that gives you information about patchiness of habitats along the line, as well as inside/out, before and after.

Gary Davis: There was a suggestion about monitoring threats, if these are what we want to remove then how do we do it?

Janet Slater: For threats to habitats, you can pick up changes from video transects. They are qualitative but a good overall record.

Tim Lynch: Are strip transects good for this or should you map the whole area?

Matthew edmunds: Some of there changes can be picked up from quadrat data.

Laurie Ferns: You can do spatial analysis on the transect data and fill in the blanks using aerial census.

Malcolm Haddon: At Leigh they produced detailed habitat maps, and this was used to document changes due to *Ecklonia* die off. That was mapped from intensive physical census work.

Nick Otway: Those maps took many years to do and required a very substantial effort.

Sam Ibbott: The use of dive-tracker technology can vastly improve our ability to make these types of maps though. You can accurately record position(cm scale) depth and enter other attributes such as algal cover. The cost is about $27000.

Gary Davis: At the landscape scale you can use sidescan sonar to map physical characters. In the Californian study we are mapping our reserve, but have not finished it yet.

Colin Buxton: They made extensive use of side scan sonar in South Africa, and it depends on what you want to measure, but it is generally just physical habitat. Reef complexity, sand and seagrass, rather than algal canopies or other biological features you might want to examine for change.

Gary Davis. In the US it has primarily been used to identify areas for dive surveys.

Leanne Gunthorpe: If you are using satellite imagery you need extensive ground truthing. In Victoria the Landsat images were very unreliable.

Malcolm Haddon: At a recent ASFB conference there was a presentation on using Landsat images. For mangrove and intertidal mapping they were fine.

Leanne Gunthorpe: Intertidal is fine, it is the subtidal where you run into problems, especially with things like cloud cover, water clarity, and the rectification of images.

Gary Davis: With the dive-tracker, has there been any repeated work? It looks like most of this has been opportunistic and not aimed at looking at long term changes. So what time frames do people think are appropriate for landscape monitoring?

Laurie Ferns: Ten years

Nick Otway: NSW management plans are updated every five years so that scale would be good.

Laurie Ferns: They could be triggered from transect work.

Tim Lynch: Some habitats are very dynamic so you might miss a lot of change at 5-10 years.

Graham Edgar: In the last part of this session we are particularly interested in comments about out methodology, especially from the FRDC point of view.

Malcolm Haddon: Why were your sites at Maria Island all about one kilometre apart?

Graham Edgar: They were not intended that way. Much of the protected part of the Maria Island coast is covered in beaches, so the area available for fitting in transects really determined where they are positioned.

Malcolm Haddon: The idea of replicates is repeated samples of sites, but you need the maximum number of sites within locations. By maximising the number of replicate sites you get adequate replication of what is at the sites within locations. In a hierarchial design you need balance, you need to decide how many samples you can take, and balance them out.

Graham Edgar: At Maria Island we crammed as many in as we could. Nearly half the reef area is covered (at 5 m). In fact we have problems with other groups doing research in the same area because of the lack of space. Some of this has been unwanted intrusive research.

Malcolm Haddon: It sounds like you have got as much power at the replicate of site level as possible. Have you got equivalent multiple sites outside that are sufficiently similar to answer the question?

Graham Edgar: In a sense we tried to address that. We sampled a lot of extra sites and using similarity indices and MDS, picked out the closest matching sites to the reserve sites and used them.

Malcolm Haddon: That is fine at the start, but can be a problem afterwards if areas diverge. Also when a good area is picked for a reserve but is surrounded by different habitats there can be problems finding external reference sites.

Graham Edgar: That is a general problem. Often areas are chosen because they are the favourite dive sites, and these are usually favourite sites for a reason relating to habitat type.

Malcolm Haddon: So what do we do to make samples representative and how many sites do we need to take within locations?

Colin Buxton: We are one step ahead here though. We need to look at transect methodology on its own and ask is the methodology capable of detecting the differences, and then also look at the application of the methodology in terms of if it is representative or not. If some other method is more appropriate we want to choose that method and work out how to apply it.

Malcolm Haddon: How do you select between methods? There is a consistent bias from each particular view, although relative abundances for comparisons may be fine.

Gary Davis: Just looking at transects for counting, how do we array plots on the landscape to make sure they are representative?

Nick Otway: You can stratify sampling into habitats, and sample type can depend on the habitats, partitioning habitats into strata.

Matthew Edmunds: If there is a lot of strata it can take a lot of time to set-up and to repeat.

Colin Buxton: Cost effectiveness is the aim, so sampling designs need to be simple.

Malcolm Haddon: There is also the effect factor of what you measure. We need some data out of a particular method to see what types of data come out, to further design the studies. We need to learn from what we have, to design future studies.

Graham Edgar: We really need to examine the information we have now, before techniques are standardised.

Laurie Ferns: Does a technique have to be standardised rather than area related? Perhaps the techniques chosen should vary from area to area depending on local conditions.

Nick Otway: In NSW there are difficulties encountered in stratifying transects into levels such as crevice/barren/*Ecklonia*. But there is a need to stratify and that is how it has been done in NSW before.

Malcolm Haddon: Some definition of methodology is needed to ensure there isn't an infinite project, you need to gather some information and check the power from that to understand variability. With fixed transects, you need to know that they are representative of an area and think carefully about where to put them. In general, it would be good to have both fixed and random transects. The current transect methodology appears fine, hard data is now becoming available, what we need is good data on alternatives to allow comparison.

Gary Davis: Once a time series is established on fixed transects and you see them moving with each other in a pattern, you can be sure they are telling you a story. If they are all moving in different directions then your sample sizes may not be sufficient to characterise a site or there is an interesting question to be answered. We will end on that note. Whichever way you approach it, a broadly based monitoring program that has the power to detect meaningful change associated with MPAs is going to be expensive.

7. Concluding Remarks - Colin Buxton

At the end of day one, I was not sure that the proceedings could easily be summarised, at the end of day two I am even less certain. There are really two perspective's represented here. There are managers whose needs include an understanding of ecological health and value, including processes that threaten these values and under the NRSMPA there are performance indicators that need to be examined. The other perspective is that of the researchers. They want to know what is best to measure and what are the most appropriate design criteria. There has been no resolution of exactly the best way of meeting the differing needs, but no one here really expected that.

There has been a fair consensus on the effect-size that we want to detect, and that defines the limits of the sampling protocols used. It is important to recognise that this varies from place to place, and that no methodology will fit all situations. There were some interesting accounts yesterday of how long-term monitoring is conducted in California and the GBR, and Gary made the significant comment that you can't fund monitoring programs on short-term survey money. This needs to be built into the strategic plans of funding programs and we have a long way to go to get that message across. This is evident by the fact that using the term “monitoring” in a grant application is almost to guarantee the application will fail.

It was significant that both Hugh and Gary estimated data management to be between 30-40% of the total cost of on-going programs, and that Hugh recommended the use of off-the-shelf packages rather than to develop in-house databases. The latter have been expensive and need dedicated staff. In general you need good quality control and adequate training.

Mick Keough contributed valuable advice on logical sampling design, knowing what you want to detect, fitting an appropriate model, knowing the decision making rules, and optimising samples to give you the best value for money. One other point was that getting professional statistical advice was, or should be, an integral part of a monitoring program. Data are often not normal, and new methods of examining this type of data are being developed all the time. When developing monitoring programs we need confidence that the data will detect the changes we consider are important.

Gary has attempted to focus a discussion on methods and there was general agreement that methods need to be cost-effective and non-destructive. There was an interesting interchange between managers and biologists and it is clear that managers need to carefully consider the questions they want answered, and that the scientists need to further examine the ways of doing this.

8. Acknowledgements

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9. Appendix 1 – Detailed Methodology (adapted from the Victorian NRE standard operating proceedures for reef surveys).

The underwater visual census methodology described here is that currently in use in Tasmania, Victoria, New South Wales and Western Australia for assessing population structure and biodiversity on temperate reef systems. It was developed for assessing the effectiveness of Tasmanian MPAs (Edgar and Barrett 1997, 1999), and based on commonly used techniques (e.g., Russell 1997, McCormick and Choat 1987, Lincoln Smith 1988, 1989). The suitability of this methodology for assessing the magnitude of biotic change in temperate MPAs was the focus of the workshop. The methodology has been developed within the framework of being non-destructive (for use in MPAs) and gathering as much data as possible on a wide range of species, including fishes, invertebrates and macroalgae. This broad census of biota allows changes to be examined at the species level (for fished, bycatch or key species) and more widely at the biodiversity and ecosystem levels.

The following methodology is an edited and abbreviated version taken from the Standard Operating Procedure Manual developed by NRE Victoria for conducting biotic surveys on Victorian reef systems.

Observing conditions.

Sampling is restricted to between 0900 and 1600 hours in winter and between 0830 and 1700 in summer to avoid poor lighting because of low sun angle. Fish censuses are not attempted for visibility less than 5 m. This is because fish tend to be extremely diver wary and skittish in low visibility conditions, and the detectability of various species is likely to be affected. Accuracy of transect setting and diver safety are also compromised in low visibility conditions.

Location of Sampling Site.

The central position of sampling sites are usually located with dGPS which maintains an accuracy of ± 5 m. The position is marked with a weighted buoy line and the boat is anchored nearby. All coordinates are recorded using the Australian Geodetic Datum 1966 (the standard datum of Australian Admiralty and Hydrographic Charts).

Many sites are positioned immediately adjacent to distinctive natural features (such as underwater bombies or rocky outcrops on the shoreline). At these sites it is possible to accurately position the marker when use of the dGPS system is not possible due to the unavailability of satellites and operation of ‘selective availability’ by the USA defence administration. Sites that can only be located accurately with a dGPS cannot be sampled on days when satellites are unavailable.

Dive Survey Procedure.

1. Divers gear-up on the boat, methods and transects are assign to each observer and the direction of the first transect (T1) is confirmed.
2. Two divers descend to the marker weight with the transect reels, clip the ends off and swim off in opposite directions along the same depth contour, unreeling the 100 m transect lines as they go (see Figure 1). Transects are conducted along a fixed depth contour (usually 5 or 10 m) to minimise depth related variability within and between sites. The divers swim above the kelp canopy (where present), navigating using a depth gauge, compass and familiar underwater features. Care is taken to ensure the transect line will be at the desired depth once it settles beneath the kelp canopy.
3. The resulting 200 m of transect line (with the marker in the centre) is divided into four 50 m contiguous transects, and labelled T1 (ie for transect 1), T2, T3 and T4 (Figure 2). The transect line is numbered every metre (colour coded for each 10 m section), has a lead weight every 5 m and two lead weights at 50 m. The direction of T1 is fixed, being the same for each survey at each site. In general, the direction of T1 is in an anti-clockwise direction around the coast (ie in a general easterly direction).
4. To minimise diver disturbance, fish surveys are always completed first, and the divers movements are organised so that no diver moves through an area being surveyed by another diver.
5. Once the transect line is set, the divers commence the fish census. Two or more divers may be involved at this stage.
6. Once fish counts are completed the diver responsible for the algal quadrat survey (Census Method 3) then commences from the start of T1, sampling through to the end of T4. The same diver records *Macrocystis* abundance (Census Method 4).
7. Divers responsible for the invertebrate and cryptic fish survey (Census Method 2) work in a T4 to T1 (easterly) direction along their assigned transects.
8. At the completion of the census, the diver responsible for the algal survey winds up the transect line from T4 to the central marker and the diver responsible for the invertebrate survey of T1 winds up the transect line from T1 to the central marker.

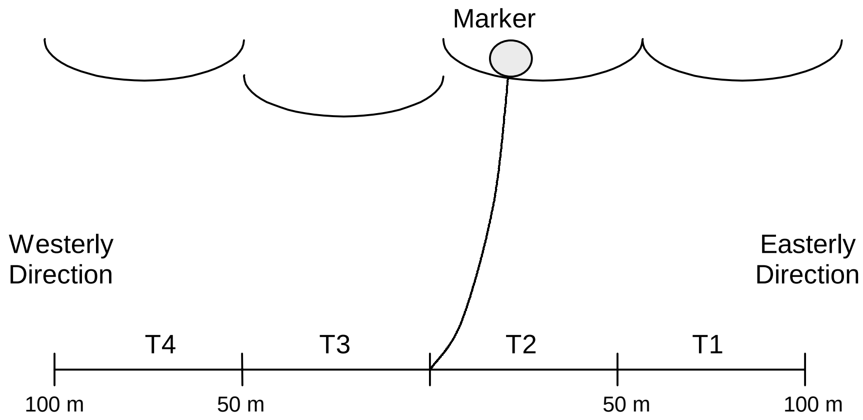

Figure 1: Arrangement of transects for underwater visual censuses (not to scale).

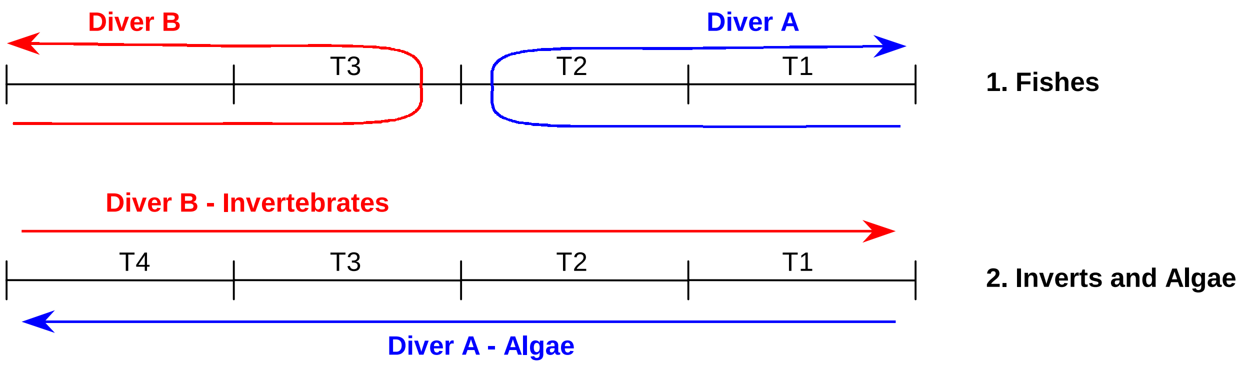

Figure 2: Typical sequence of surveys using two divers. Divers A and B reel out transect line.

Census Method 1 – Mobile Fishes and Cephalopods

Mobile large fishes and cephalopods are censused within 5 m wide lanes each side of the transect line. Each transect line is composed of four 10 x 50 m contiguous sections as outlined in Figure 2.

1. The diver swims directly to the start point of the transect. The direction and order of transects is designed to minimise diver disturbance/attraction of fish.
2. The diver swims along the offshore (deeper) side of the transect first then returns on the shallower side.

3. The dive observer swims down an imaginary line 2.5 m from the transect line. This distance is approximately one body length (with fins) and estimation of this distance is calibrated by sighting down the transect line to halfway between the line-weights (which are 5 m apart).
4. The dive observer swims just above the kelp canopy (where there is one) and scans forward into the visible area. The observations include looking into the kelp canopy, visible crevices and caves, on top of bombies and the water column.
5. The dive observer swims as slowly as feasible, but without stopping (as any fish following the diver will move into the field of view).
6. The dive observer records the number and size of each species of fish and cephalopods sighted within the 5 m census belt.
7. Fish sizes are recorded in size categories: 25, 50, 75, 100, 125, 150, 200, 250, 300, 350, 375, 400, 500, 625, 750, 875 and 1000^{+} mm. A scale ruler is on the underwater slate for calibration of size estimates.
8. As each individual is sighted, a mark is placed on the field sheet in the appropriate size category on the appropriate species line.
9. The data for easily sexed species is recorded separately for males and female/juveniles. Such species include the blue throated wrasse *Notolabrus tetricus*, senator wrasse *Pictilabrus laticlavius*, rosy wrasse *Pseudolabrus psittaculus*, eastern blue groper *Achoerodus viridis*, herring cale *Odax cyanomelas*, barber perch *Caesioperca rasor*, six-spine leatherjacket *Meuschenia freycineti*, toothbrush leatherjacket *Acanthaluteres vittiger* and other monacanthids.
10. Once a fish is sighted and recorded it is ignored, even if it is seen leaving and immediately re-entering the census area.
11. Only fish sighted within the census area are recorded, fish seen moving into the census area are ignored.
12. Easily recognisable fish that circle the diver throughout the census, particularly male *Notolabrus tetricus* are ignored after the initial sighting.
13. For dense aggregations or schools, the abundance is estimated using the approximate volume of 10 - 20 counted fish (the abundance therefore written in 10s or 100s).
14. The characteristics of unidentified species are noted on the field sheet. Species are determined immediately after the dive from discussions with other observers, or at the end of the day by using reference texts.

Census Method 2 – Invertebrates and Cryptic Fishes

Cryptic fishes and megafaunal invertebrates (non-sessile: eg large molluscs, echinoderms, crustaceans) are counted along the transect lines used for the fish survey. Each transect line is composed of four 1 x 50 m contiguous sections as outlined in Figure 2.

1. The dive observer starts each invertebrate transect at the westerly (T4) end and heads in a general easterly direction towards the end of T1. This search direction is fixed for all sites.

2. The dive observer carefully searches the substratum for invertebrates and cryptic fishes within 1 m of the transect line, on the shoreward (shallower) side of the transect.
3. The macroalgae are swept aside to obtain a clear view of the substratum, with the dive observer often proceeding along the transect beneath the kelp canopy.
4. All crevices are investigated to the best of the dive observer's view.
5. A pole is carried by the dive observer to standardise the 1 m distance. However, each dive observer also has a known body distance for transect width checking and calibration (such as left fingertip to right buckle of the dive observer's Buoyancy Control Device) – this method being more practical to apply in thick kelp and difficult ground swell.
6. All non-sessile invertebrates > 20 mm within the transect lane are counted, including decapod crustaceans (crabs, rock lobster and hermit crabs, but excluding shrimps), gastropods, bivalves (mainly scallops), octopus, crinoids (feather stars), asteroids (seastars), echinoids (sea urchins) and holothurians (sea cucumbers).
7. Annelids (worms), polyplacophorans (chitons), shrimps and ophiouroids (brittle stars) are not counted as they are mostly cryptic and too numerous (and therefore cannot be properly enumerated in a multi-species census).
8. Unknown or unidentifiable invertebrate species are placed in the catchbag, with a corresponding note on the field sheet, and taken to the surface for further examination.
9. Cryptic and sedentary fish are counted, including cryptic juvenile stages of large mobile species counted in the fish census. The size of individuals is recorded, as with the fish census. Cryptic species include members of the Parascyllidae, Urolophidae, Muraenidae, Sygnathidae, Scorpaenidae, Apogonidae, Pempherididae, Gnathanacanthidae, Pomacentridae (juveniles), Bovichtidae, Tripterygiidae, Clinidae and Gobiidae families.
10. The number and of *Haliotis* spp (abalone) individuals is recorded for each transect. The size of individual abalone is measured *in situ* with callipers by the maximum shell length. All abalone are measured until the sample size is at least 36 individuals or the transect is finished. (Note that those individuals that are inaccessible for measurement are still counted).
11. For sites where the reef habitat exhibits very high abalone densities (> 150 - 200 per 200 m^2) measure a minimum of 100 abalone. For lower density sites where less than 100 abalone are measured between T1 and T4, additional measurements are taken from the nearest abalone aggregation to the transect, taking care to measure all individuals within a crevice or patch to ensure unbiased selection.

12. The carapace length of *Jasus* spp (rock lobsters) individuals is estimated *in situ*. Callipers are held as close as possible to the individual to improve accuracy and precision of measurement. Sex is recorded where observable. If individuals can be easily handled without loss of appendages and stress to the animal, then the carapace length is measured properly and sex determined. Catching and excessive handling of animals does not occur to prevent long-term affects of the surveys on resident populations.

Census Method 3 – Macrophytes

The area covered by macroalgal species is quantified by placing a 0.5 x 0.5 m quadrat at 10 m intervals along the transect line and determining the percent cover of the all plant species (refer Figure 3). Twenty quadrats are sampled per site.

1. The dive observer starts the algal quadrats at the easterly (T1) end and heads towards the end of T4. This quadrat order is fixed for all sites.
2. The first quadrat is placed at the 100 m mark on T1, with subsequent quadrats placed at 10 m intervals (indicated by numbers on the transect line and line weights). No quadrat is sampled at 0 m.
3. Each quadrat is placed on the offshore side of the transect (opposite to the invertebrate transect), with the top edge of the quadrat running along the transect line, and the marker weight in the centre of this edge.
4. The quadrat is divided into a grid of 7 x 7 perpendicular wires, giving 50 points (including one corner). The number of quadrat points covering each species is counted.
5. The quadrat is first held over the kelp canopy, and the points-cover of each canopy species recorded.
6. The canopy is then swept aside, the quadrat placed on the substratum and smaller species enumerated.
7. Points-counts are recorded for each lowest identifiable taxon, usually to species level. Unknown or unidentifiable species are assigned functional categories including: ‘other thallose reds’, ‘other erect corallines’, ‘encrusting corallines’, ‘filamentous reds’, ‘filamentous browns’ and ‘other small browns’.
8. Unknown specimens are collected for examination on the surface and / or future identification by experts. However, collection of all unknown species occurring in very low densities (less than 1% of total algal cover) is not required when time is limiting. For species that are unknown but common (frequently encountered and/or reasonably high in abundance) they are denoted on the field sheet as a separate species (with a temporary name) and a representative specimen is collected. The specimen is subsequently curated and identified, with the field sheet and database amended accordingly.

Census Method 4 – *Macrocystis*

The density of *Macrocystis angustifolia* plants is estimated for ten 100 m^2 sections of the transect at each site.

1. *Macrocystis* plants are counted by the same dive observer doing the algal quadrats, as the dive observer swims between each 10 m quadrat. Individual *Macrocystis* are readily distinguished from other species in the canopy by their lighter colour and morphology. In some instances, individuals are distinctly higher than the kelp canopy, sometimes forming an over-storey at the surface.
2. The dive observer swims along the transect, counting all observable plants within 5 m either side of the line between quadrat stations.
3. The estimation of 5 m distance is calibrated by positioning at a transect line weight, and sighting down the transect to the next line weight (5 m away).

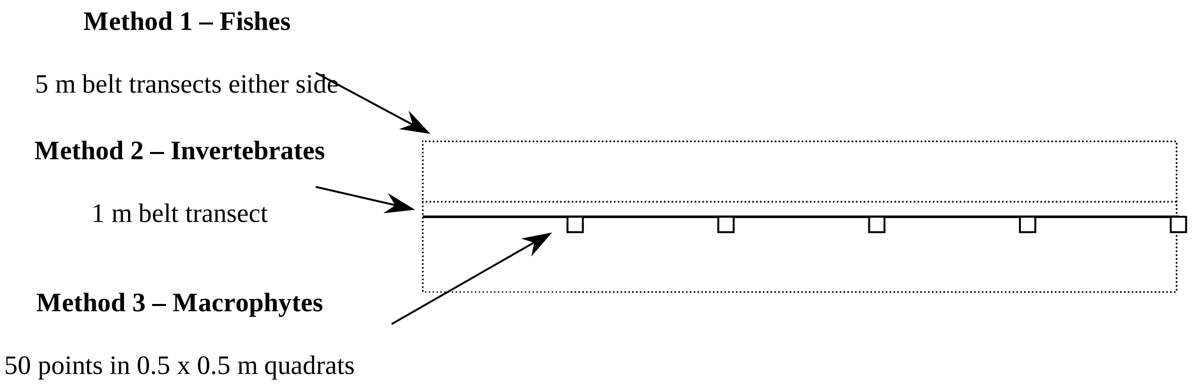

Figure 3. Configuration of census areas for each 50 m transect. For fishes, the deepest 5 m wide belt is surveyed first, followed by the inshore, shallower belt. For invertebrates, the inshore side of the transect is surveyed. For macrophytes, quadrats are placed on the offshore side of the transect, with the top of the quadrat running along the transect line and with the transect marker weight in the centre of the top edge.

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